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Sedimentology, Depositional Age, and Provenance of Sedimentary and Volcanic Rocks Exposed Along Willow Creek, Eastern Susitna Basin, South-Central Alaska: Implications for Modification of a Forearc Basin by Spreading Ridge Subduction

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SEDIMENTOLOGY, DEPOSITIONAL AGE, AND PROVENANCE OF SEDIMENTARY AND VOLCANIC ROCKS EXPOSED ALONG WILLOW CREEK, EASTERN SUSITNA BASIN, SOUTH-CENTRAL ALASKA: IMPLICATIONS FOR MODIFICATION OF A FOREARC BASIN BY SPREADING RIDGE SUBDUCTION

by

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ABSTRACT

Upper Paleocene–Eocene sedimentary and volcanic strata of the Arkose Ridge Formation exposed in the southern Talkeetna Mountains record fluvial-lacustrine deposition in a forearc basin modified by Paleogene spreading ridge subduction beneath southern Alaska. This is the first detailed study of the westernmost portion of the outcrop belt, which extends along the western flank of the Talkeetna Mountains and includes thick, well-exposed outcrops along Willow Creek in the eastern Susitna basin. New sedimentologic, compositional, and geochronologic data were obtained from stratigraphic sections within Arkose Ridge Formation strata at Willow Creek. This data combined with new geologic mapping and geochronologic data from Willow Bench and Kashwitna River Bluff (north of Willow Creek), and from the Government Peak area (east of Willow Creek), help constrain depositional processes and source terranes that provided detritus to the westernmost Arkose Ridge Formation strata.

Westernmost Arkose Ridge Formation strata at Willow Creek unconformably overlie a granitoid pluton that yields Late Cretaceous U-Pb zircon ages (79–69 Ma; 74 total grains from three samples). Four lithofacies associations characterize the 467 meter thick Arkose Ridge Formation outcrop at Willow Creek: poorly sorted, boulder-pebble conglomerate with minor channelized sandstone (FA1); poorly to moderately sorted, cobble-pebble conglomerate with imbricated conglomerate and channelized sandstone (FA2); channelized sandstone with scours, cross-stratification, and carbonaceous debris (FA3); and basaltic-andesitic lava flows with massive bases and vesicular tops (FA4). Conglomerate detrital modes are dominated by volcanic clasts (60% of all clasts) and

plutonic clasts (31%) with three granitoid clasts from FA1 yielding Latest Cretaceous (81–69 Ma), early Late Cretaceous (89–82 Ma), and Early Jurassic to Latest Triassic (215–190 Ma) U-Pb zircon ages. U-Pb ages of 189 detrital zircon grains in two sandstone samples reveal three main populations: Latest Cretaceous to Early Paleocene (85–60 Ma; 63% of all grains); early Late Cretaceous (100–85 Ma; 30%) and Early Cretaceous to Jurassic (200–100 Ma; 5%). Sparse Late Paleocene (59–58 Ma; 2%) detrital zircon ages constrain the maximum depositional age of the Willow Creek strata to <59 Ma. U-Pb ages of 160 detrital zircon grains from two Arkose Ridge Formation sandstone samples from the Government Peak area, 20 km southeast of Willow Creek, reveal a single Late Cretaceous (97–69 Ma; 100%) age distribution and the underlying granitoid pluton yields Late Cretaceous U-Pb zircon ages (86–79 Ma; 24 total grains from one sample). New geologic mapping at Kashwitna River Bluff and Willow Bench document Paleogene aphanitic, black lavas unconformably overlying the Cretaceous granitoid pluton.

Collectively, these new compositional and geochronologic data from Willow Creek and adjacent areas suggest: (1) Sediment was deposited by debris flow, hyperconcentrated flow, and streamflow on high-gradient braided streams influenced by episodic volcanic eruptions. (2) Local Cretaceous plutons and Paleogene volcanic centers at Willow Bench and Kashwitna River Bluff were important sediment sources. (3) Deposition took place after ca. 59 Ma, consistent with 60–56 Ma isotopic ages reported from volcanic interbeds in eastern parts of the outcrop belt. (4) Exhumation of

Cretaceous granitoid underlying and exposed north of the Willow Creek section occurred by 59 Ma followed by subsidence coeval with erosion between 59–55 Ma.

The history of exhumation and sediment accumulation documented in this study and previous studies is consistent with the expected effects of spreading ridge subduction, a second order tectonic process that modified the region's configuration and depositional processes from traditional forearc basin models. Paleogene subduction of young oceanic crust beneath the Cretaceous magmatic arc would prompt increased compressive stress, rock uplift, and unconformity development in the upper plate followed by forearc subsidence and sediment accumulation (Arkose Ridge Formation) during passage of a slab window and progressively older crust. Integration of geochronologic and compositional data from Willow Creek with previous studies in the southern Talkeetna Mountains provides insight on the complex lateral variations in provenance and depositional environments in a forearc basin during a well-documented episode of spreading ridge subduction.

INTRODUCTION

Structural and stratigraphic relationships within forearc basin deposits record the long-term depositional history and tectonic processes that shape convergent plate margins. Forearc basins are large sedimentary basins that form between deep trench axes, related to subduction zones, and parallel active magmatic arcs, correlated to melting of the subducted oceanic plate (Dickinson, 1995). Previous studies document this spatial relationship as the "forearc trinity" which consists of a magmatic arc, forearc basin, and subduction complex and forms as a first-order response to subduction along convergent margins (Dickinson, 1995). A conventional model for sediment deposition within forearc basins, defined by this configuration, predicts a progressive succession from deep-marine through shallow-marine to nonmarine deposystems with continued filling of the basin (Ingersoll, 1979; Dickinson, 1995). Previous studies on forearc basin development have focused primarily on marine deposits, with a general lack of literature documenting nonmarine deposits (Dickinson, 1995). Also overlooked in the evolution of forearc basin development is the influence of second-order tectonic processes, such as flat-slab subduction of thickened oceanic crust, including spreading ridges and oceanic plateaus. Flat-slab subduction can significantly modify the configuration and depositional processes within forearc basins such that they do not coincide with the forearc trinity model (Finzel *et al*., 2011; Ridgway *et al*., 2012). Cretaceous to Oligocene strata exposed in the Matanuska Valley-Talkeetna Mountains forearc basin in south-central Alaska (Fig. 1) provide a long-term record of the evolution of a sedimentary basin from marine deposition during “normal” subduction of oceanic crust to flat-slab subduction of a spreading ridge during Paleocene–Eocene time and an oceanic plateau during Oligocene time (Trop and Ridgway, 2007; Finzel *et al*.,2011). Recent studies demonstrate that ridge subduction is a common process that shapes convergent plate margins (e.g. Madsen *et al*., 2006; Thorkelson *et al*., 1989). However, the impact of ridge subduction on forearc basin landscape evolution and sediment accumulation remains largely unexplored.

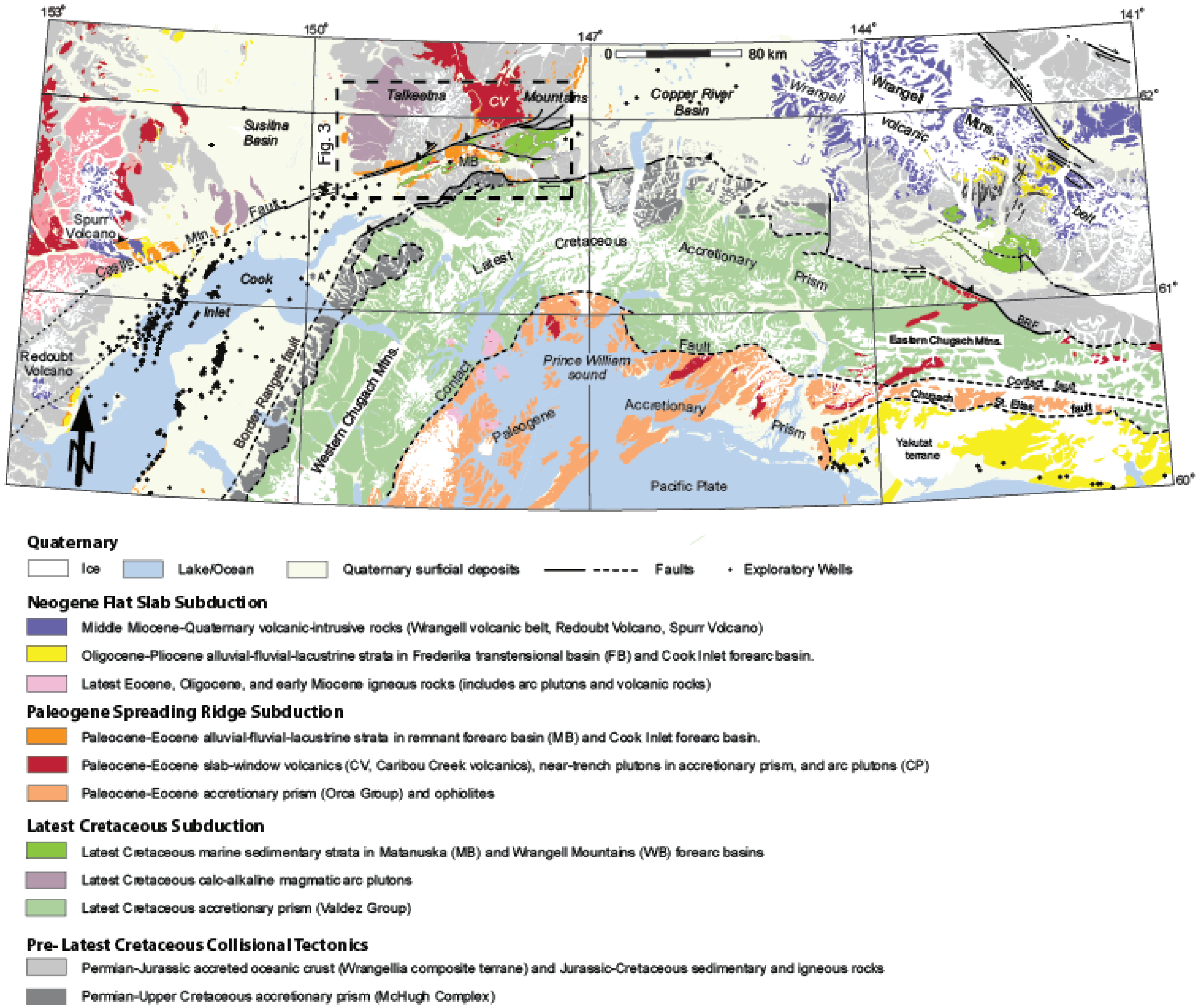
Basinal strata in the Matanuska Valley-Talkeetna Mountain forearc basin include Paleocene–Eocene nonmarine sedimentary and volcanic strata deposited in fluvial-lacustrine depositional environments (Little, 1988; Trop *et al.,* 2003; Trop and Ridgway, 2007). Forearc basin strata are bounded by Jurassic–Cretaceous remnant arc plutons to the north, the Eocene Caribou Creek volcanic center to the northeast, and the Mesozoic meta-sedimentary rocks of the Chugach subduction complex to the south (Fig. 1). Previous research documents regional marine deposition in an elongate forearc basin with erosion of the associated Jurassic–Cretaceous magmatic arc across most of southern Alaska (Trop, 2008), consistent with conventional forearc sediment depositional models. Modification of sediment deposition in the forearc basin by second-order tectonic processes, such as spreading ridge subduction, is apparent by the cessation of arc magmatism, emplacement of localized slab-window volcanic centers, and partitioning of the forearc basin into nonmarine depocenters. Near-trench plutons document the west-to-east migration of a spreading ridge as it was subducted with ages of 62 Ma in the west and 50 Ma ages in the east where the Caribou Creek Volcanic Center crops out (Fig. 2). The construction of the Caribou Creek Volcanic Center (CCV) is attributed to slab-window magamatism during this spreading ridge subduction event based largely on interpreted geochemical and geochronologic datasets (Cole *et al.,* 2006).

Previous studies document nonmarine sedimentary strata deposited in localized depocenters linked to the construction of slab-window volcanic centers (Trop *et al*., 2003; Kortyna, 2011). Sedimentary and volcanic strata exposed along Willow Creek in the eastern Susitna basin are mapped as Arkose Ridge Formation (Wilson *et al*., 1998), but no previous geochronological or stratigraphic data have been reported prior to this study (Fig. 3). This is the first detailed study of the poorly understood westernmost portion of the Arkose Ridge Formation outcrop belt, which extends approximately 90 km along the western flank of the Talkeetna Mountains and includes thick, well-exposed outcrops along Willow Creek. The purpose of this study is to integrate geologic mapping, detrital geochronologic analyses, sedimentologic data, and compositional data from Willow Creek to previously collected data in the Talkeetna Mountains to better understand how deposystem processes and provenance change along strike in the Matanuska Valley-Talkeetna Mountain forearc basin during a well-documented episode of spreading ridge subduction.

GEOLOGIC AND DEPOSITIONAL FRAMEWORK

The 90-km-long and 20-70-km-wide Matanuska Valley-Talkeetna Mountain forearc basin consists of Middle Jurassic–Oligocene sedimentary strata exposed in the Matanuska Valley, southern Talkeetna Mountains, eastern Susitna basin, and northern Chugach Mountains (Fig. 1; Trop and Plawman, 2006; Trop, 2008). The forearc basin is bounded to the north by two remnant magmatic arcs as a result of the Mesozoic collision of a Jurassic oceanic island arc followed by Late Cretaceous–Paleocene continental arc magmatism (Rioux *et al.*, 2007). Basinal strata are also bounded by the Eocene Caribou Creek volcanic center to the northeast (Cole *et al.*, 2006), Paleogene mafic volcanic centers to the northwest, and Mesozic meta-sedimentary rocks of the Chugach subduction complex to the southeast (Fig. 3; Trop and Ridgway, 2007). The Arkose Ridge and

Figure 1. Generalized geologic map of south-central Alaska showing features attributable to latest Cretaceous "normal" subduction, Paleocene and Eocene flat-slab subduction of a spreading ridge, and Oligocene-Holocene subduction of the Yakutat microplate. From Ridgway *et al.* (in press). Dashed black line shows map location of Figure 3. Abbreviations: A-Anchorage; BRF-Border Ranges fault; CV-Caribou Creek volcanic field; MB-Matanuska basin; and WB-Wrangell Mountains basin. Black circles denote oil/gas exploration wells. Thin black lines define 1:250,000 quadrangles. Map adapted from Wilson *et al*, (1998).



153°
150°
147°
144°
141°
62°
61°
60°
0
80 km
Talkeetna
CV
Mountains
Copper River Basin
Wrangell
Wrangell
volcanic
Mtns.
belt
Susitna Basin
Fig. 3
MB
Fault
Spurr Volcano
Castle
Mtn
Cook
Inlet
A'
Latest
Cretaceous
Accretionary
Prism
BRF
Eastern Chugach Mtns.
Redoubt Volcano
Border Ranges fault
Western Chugach Mtns.
Contact
Prince William sound
Fault
Accretionary
Prism
Paleogene
Contact
fault
Chugach
St. Elias
fault
Yakutat terrane
Pacific Plate
N
Quaternary
Ice
Lake/Ocean
Quaternary surficial deposits
Faults
Exploratory Wells
Neogene Flat Slab Subduction
Middle Miocene-Quaternary volcanic-intrusive rocks (Wrangell volcanic belt, Redoubt Volcano, Spurr Volcano)
Oligocene-Pliocene alluvial-fluvial-lacustrine strata in Frederika transtensional basin (FB) and Cook Inlet forearc basin.
Latest Eocene, Oligocene, and early Miocene igneous rocks (includes arc plutons and volcanic rocks)
Paleogene Spreading Ridge Subduction
Paleocene-Eocene alluvial-fluvial-lacustrine strata in remnant forearc basin (MB) and Cook Inlet forearc basin.
Paleocene-Eocene slab-window volcanics (CV, Caribou Creek volcanics), near-trench plutons in accretionary prism, and arc plutons (CP)
Paleocene-Eocene accretionary prism (Orca Group) and ophiolites
Latest Cretaceous Subduction
Latest Cretaceous marine sedimentary strata in Matanuska (MB) and Wrangell Mountains (WB) forearc basins
Latest Cretaceous calc-alkaline magmatic arc plutons
Latest Cretaceous accretionary prism (Valdez Group)
Pre-Latest Cretaceous Collisional Tectonics
Permian-Jurassic accreted oceanic crust (Wrangellia composite terrane) and Jurassic-Cretaceous sedimentary and igneous rocks
Permian-Upper Cretaceous accretionary prism (McHugh Complex)

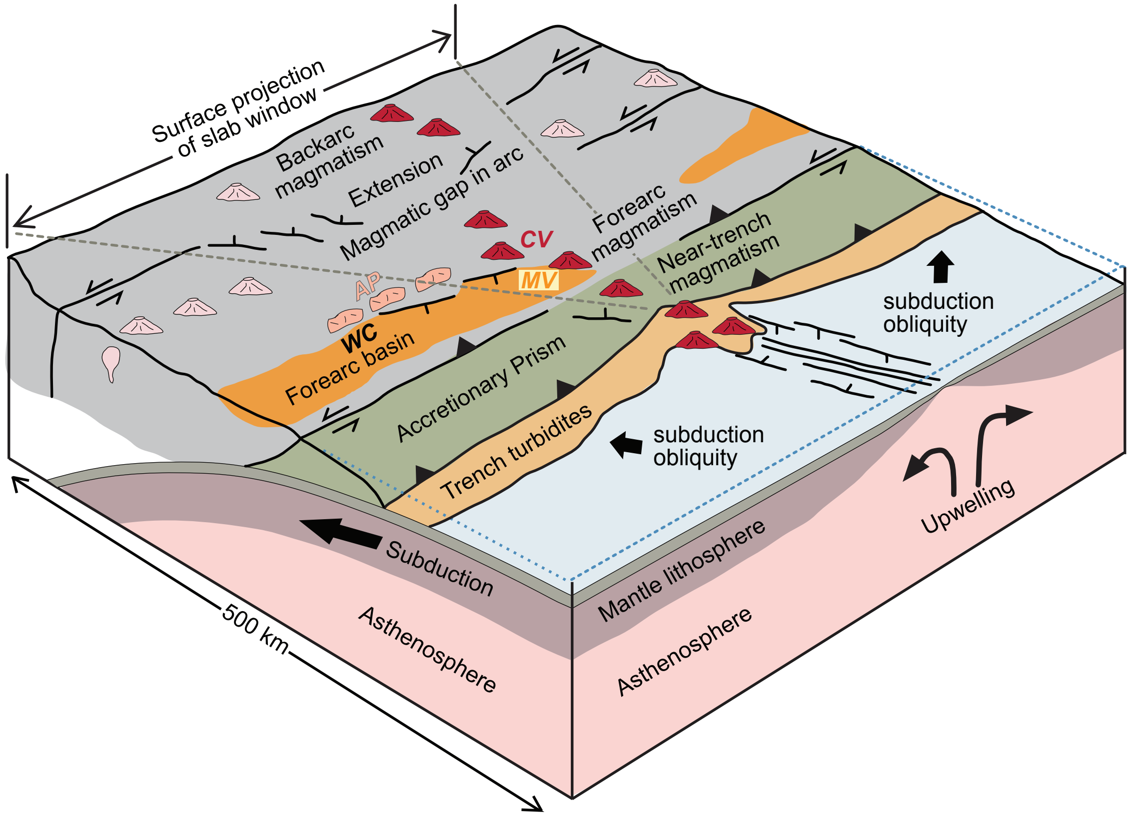
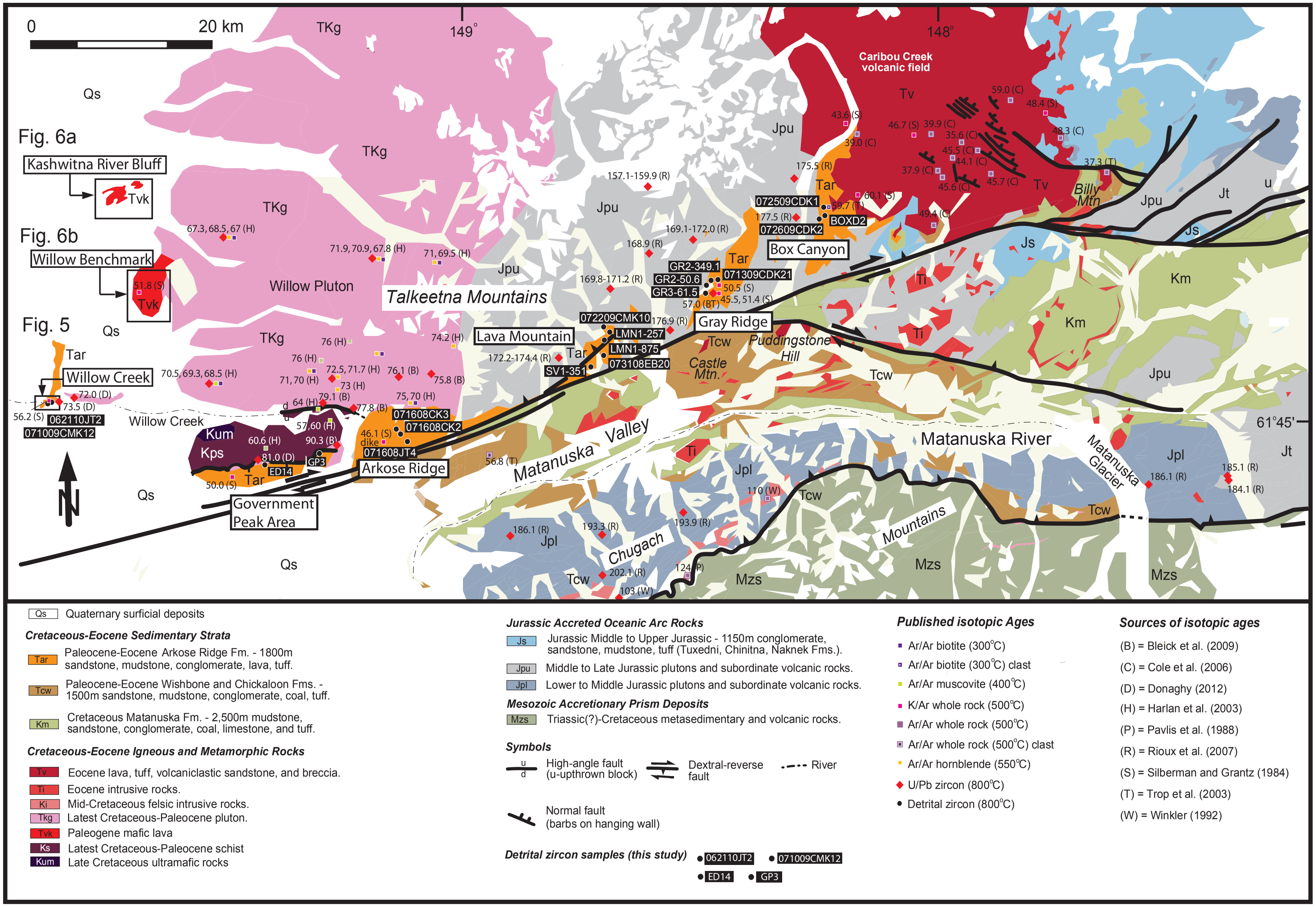


Figure 2. Schematic block diagram illustrating inferred geologic effects of ridge subduction in south-central Alaska. Spreading ridge subduction produces a slab window that juxtaposes hot asthenosphere against cold base of forearc lithosphere. The lack of a plate beneath the arc axis prevents subduction-related arc magmatism. Oblique convergence prompts motion along margin-parallel strike-slip faults. Forearc basin subsidence and sediment accumulation reflects deformation along normal faults associated with slab window extension and exhumation along margin-parallel strike-slip faults. Note inferred position of Willow Creek (WC) within the Paleocene-Eocene Matanuska Valley forearc basin (MV), Cretaceous to Jurassic remnant arc plutons (AP) and slab window volcanics of the Caribou Creek volcanic field (CV; Cole et al., 2006). See Figure 1 for basin location and regional extent of near-trench plutons. Adapted from Bradley *et al.* (2003).

Figure 3. Enlarged generalized geologic map of the southern Talkeetna Mountains, Matanuska Valley, and northern Chugach Mountains. Adapted from Wilson *et al.* (1998). This study focuses on Paleogene fluvial-lacustrine strata exposed north (orange-Tar) of the Castle Mountain fault that record erosion of local igneous source terranes. Cretaceous-Jurassic magmatic arc rocks crop out in the southern Talkeetna Mountains along the Castle Mountain fault (TKg - pink color; Jpu - light gray). Paleogene volcanic (dark red-Tv) and intrusive (red-Ti) igneous rocks are attributed to slab window magmatism. Westernmost volcanic rocks (red-Tvk) are attributed to fissure eruptions as a result of new mapping data from this study (Fig. 6). These volcanic rocks were emplaced broadly coeval with deposition of the Arkose Ridge Formation (orange-Tar). See Figure 1 for map location.


0 20 km
149°
148°
61°45'
Fig. 6a
Kashwitna River Bluff
Fig. 6b
Willow Benchmark
Fig. 5
Willow Creek
Willow Pluton
Talkeetna Mountains
Caribou Creek volcanic field
Lava Mountain
Gray Ridge
Box Canyon
Billy Mtn
Puddingstone Hill
Castle Mtn.
Arkose Ridge
Government Peak Area
Matanuska Valley
Matanuska River
Matanuska Glacier
Chugach Mountains
062110JT2
071009CMK12
ED14
GP3
071608CK3
071608CK2
071608JT4
SV1-351
072209CMK10
LMN1-257
LMN1-875
073108EB20
GR2-349.1
GR2-50.6
GR3-61.5
071309CDK21
072509CDK1
072609CDK2
BOXD2
Qs Quaternary surficial deposits
Cretaceous-Eocene Sedimentary Strata
Tar Paleocene-Eocene Arkose Ridge Fm. - 1800m sandstone, mudstone, conglomerate, lava, tuff.
Tcw Paleocene-Eocene Wishbone and Chickaloon Fms. - 1500m sandstone, mudstone, conglomerate, coal, tuff.
Km Cretaceous Matanuska Fm. - 2,500m mudstone, sandstone, conglomerate, coal, limestone, and tuff.
Cretaceous-Eocene Igneous and Metamorphic Rocks
Tv Eocene lava, tuff, volcaniclastic sandstone, and breccia.
Ti Eocene intrusive rocks.
Ki Mid-Cretaceous felsic intrusive rocks.
Tkg Latest Cretaceous-Paleocene pluton.
Tvk Paleogene mafic lava
Ks Latest Cretaceous-Paleocene schist
Kum Late Cretaceous ultramafic rocks
Jurassic Accreted Oceanic Arc Rocks
Js Jurassic Middle to Upper Jurassic - 1150m conglomerate, sandstone, mudstone, tuff (Tuxedni, Chinitna, Naknek Fms.).
Jpu Middle to Late Jurassic plutons and subordinate volcanic rocks.
Jpl Lower to Middle Jurassic plutons and subordinate volcanic rocks.
Mesozoic Accretionary Prism Deposits
Mzs Triassic(?)-Cretaceous metasedimentary and volcanic rocks.
Symbols
High-angle fault (u-upthrown block)
Dextral-reverse fault
River
Normal fault (barbs on hanging wall)
Detrital zircon samples (this study)
Published isotopic Ages
Ar/Ar biotite (300°C)
Ar/Ar biotite (300°C) clast
Ar/Ar muscovite (400°C)
K/Ar whole rock (500°C)
Ar/Ar whole rock (500°C)
Ar/Ar whole rock (500°C) clast
Ar/Ar hornblende (550°C)
U/Pb zircon (800°C)
Detrital zircon (800°C)
Sources of isotopic ages
(B) = Bleick et al. (2009)
(C) = Cole et al. (2006)
(D) = Donaghy (2012)
(H) = Harlan et al. (2003)
(P) = Pavlis et al. (1988)
(R) = Rioux et al. (2007)
(S) = Silberman and Grantz (1984)
(T) = Trop et al. (2003)
(W) = Winkler (1992)

Chickaloon Formation represent the nonmarine, fluvial-lacustrine deposits within the forearc basin. The Arkose Ridge Formation is characterized by sandstone, pebble-boulder conglomerate, mudstone, and basalt and the Chickaloon Formation is characterized by mudstone, coal, sandstone, and minor pebble-cobble conglomerates and tuff (Trop and Ridgway, 2007). The Border Ranges Fault separates the Chugach subduction complex from the southern margin of the forearc basin (Pavlis and Roeske, 2007) and the east-west striking Castle Mountain fault is the southern boundary of the Arkose Ridge Formation in the southern Talkeetna Mountains (Fig. 3). Age equivalent Arkose Ridge Formation strata to the south of the Castle Mountain fault are mapped as the Chickaloon Formation. Reactivation of these major fault systems during Eocene–Oligocene time is inferred to have resulted from the passage of a mid-ocean spreading ridge during the Paleocene beneath the forearc basin, evidenced by footwall growth synclines as a product of syndepositional displacement of the Castle Mountain Fault with forearc basin sediment deposition (Trop *et al.,* 2003; Ridgway *et al*., 2012).

Timing of the amount of dextral strike-slip displacement along the Castle Mountain fault (CMF) is poorly understood. Outcrop distribution of the Naknek Formation, Jurassic plutons, and the Little Oshneta fault system across the Castle Mountain fault provide potential piercing points for Late Jurassic–Cretaceous strike-slip displacement. Correlation across the CMF of the Oshneta fault system to the well-documented Bruin Bay fault system south of the fault would require approximately 110-130 km of dextral displacement (Trop *et al*., 2005). Late Cretaceous to Tertiary piercing points record 20-40 km of dextral offset along the Castle Mountain Fault but do not constrain timing of initial displacement (Grantz, 1996; Clardy, 1974; Detterman *et al.,* 1976; Trop *et al*., 2003). Recent studies comparing U-Pb detrital age distributions and unique lithofacies associations from the Eocene Wishbone Formation and overlying volcaniclastic strata at Castle Mountain, Puddingstone Hill (south of CMF), and Billy Mountain (north of CMF) indicating at least 43 km of dextral displacement between both locations (Szwarc *et al*,. 2011). Maximum depositional ages derived from detrital zircon geochronology (52–50 Ma) from the Wishbone Formation overlap at both Billy Mountain and Puddingstone Hill suggesting deposition as one unit in the same paleovalley prior to right-lateral slip during the Middle to Late Eocene time (Szwarc *et al*., 2011). The Castle Mountain Fault also experienced less than 3.1 km of reverse dip-slip displacement (north side up) during the Neogene time along the central part of the fault (Grantz, 1966). Therefore, Arkose Ridge and Chickaloon Formations are dextrally displaced across the Castle Mountain Fault a few tens of kilometers and have experienced reverse dip-slip displacement that brings Arkose Ridge Formation strata up in the north by several kilometers.

Upper Cretaceous–Paleogene volcanic rocks in the Talkeetna Mountains and eastern Susitna basin document three distinct phases of volcanism. Arc plutons in the south-central Talkeetna Mountains are attributed to an accreted Jurassic oceanic island magmatic arc (Talkeetna magmatic arc; 180–145 Ma) during Mesozoic time (Plafker and Berg, 1994) and arc plutons (80–60 Ma) in the southwestern Talkeetna Mountains are the result of continental arc magmatism during the Upper Cretaceous–Paleocene (Madsen *et al*., 2006; Rioux *et al*., 2007). The Upper Cretaceous–Paleocene plutons intrude the

Talkeetna magmatic arc, consistent with pluton formation attributed to a later and separate phase of magamatism distinct from the accretion of the Talkeetna magmatic arc (Trop, 2008). Spatially limited Eocene volcanic rocks of the Caribou Creek volcanic field (59–36 Ma) in the southeastern Talkeetna Mountains, Paleogene mafic volcanic centers (52 Ma; Silberman and Grantz, 1984) in the southwestern Talkeetna Mountains, and associated intrusions throughout the Talkeetna Mountains, Matanuska Valley, and Chugach Mountains are attributed to the Paleocene slab-window magmatism associated with subduction of a spreading ridge (Cole *et al*., 2006). The Arkose Ridge Formation unconformably overlies the Upper Cretaceous–Paleocene arc plutons in the west and Jurassic arc plutons in the center and interfingers with and unconformably underlies the Caribou Creek volcanic field in the east (Fig. 3; Winkler, 1992; Cole *et al.*, 2006).

Previous studies of Arkose Ridge Formation strata exposed in the southern Talkeetna Mountains document remnant arc plutons and the Caribou Creek volcanics to the north as important sources of detritus during deposition along the northern margin of the Matanuska Valley-Talkeenta Mountain forearc basin. Western and central Arkose Ridge Formation strata in the southern Talkeetna Mountains are dominated by felsic plutonic clasts and 200–60 Ma detrital grains, consistent with sediment derivation from Jurassic–Cretaceous remnant arc plutons (Kortyna, 2011). Both the Upper Cretaceous–Paleocene plutons in the west and the Jurassic plutons in the center are composed of primarily diorite, quartz diorite, granodiorite, and tonalite plutons with minor mica schist (Fig. 3; Winkler, 1992). Jurassic granitoids yield U-Pb ages of 178–169 Ma in the Eastern Talkeetna Mountains, and 153–157 Ma and 190–192 Ma ages in the Western

Talkeetna Mountains (Rioux *et al*., 2007). The Upper Cretaceous–Paleocene plutons in the western Talkeetna Mountains yield ages of 90–63 Ma (Harlan *et al*., 2003; Bleick *et al*., 2009). The Late Cretaceous–Paleocene Hatcher Pass schist is exposed in the southwestern Talkeetna (Kps on Fig. 3). The Hatcher Pass schist is greenschist-facies schist with a depositional age between 61 Ma (age of peak metamorphism based on Ar-Ar cooling ages; Harlan *et al*., 2003) and 77–75 Ma (maximum depositional age based on U-Pb zircon ages; Bradley *et al*., 2009). An east-west striking high-angle fault separates the schist from 73–67 Ma granitoid plutons to the north and a detachment fault separates the schist from Arkose Ridge Formation strata to the south (Bradley *et al*., 2009). Granitoid intrusions crop out locally along the detachment fault that separates the Arkose Ridge Formation from the schist (Winkler, 1992). The granitoids were previously interpreted as Jurassic in age (unit Jqd of Winkler, 1992) but geochronologic data have not been reported previously.

Eastern Arkose Ridge Formation strata in the southern Talkeetna Mountains are dominated by volcanic detritus and are enriched in <60 Ma detrital grains, consistent with sediment derivation from the Eocene Caribou Creek volcanic field (Kortyna, 2011). The Caribou Creek volcanic field records a depleted-mantle geochemical signature attributed to slab-window volcanism during spreading ridge subduction (Cole *et al*., 2006). The volcanic rocks consist of basalt, andesite, and felsic lavas, subordinate mafic and felsic pyroclastic deposits, and mafic-felsic intrusions and domes (Cole *et al*., 2006). The Caribou Creek volcanics that unconformably overlie Arkose Ridge Formation strata yield $^{40}Ar/^{39}Ar$ ages that range from 49.4 ± 2.2 to 35.6 ± 0.2 Ma. A tuff underlying the other Caribou Creek volcanics in the northeast yields an $^{40}Ar/^{39}Ar$ age of 59.0 ± 0.4 Ma (Cole *et al*., 2006). Maximum depositional ages (61–56 Ma) from 14 new U-Pb detrital zircon analyses of tuffs in southern Talkeetna Mountain Arkose Ridge Formation strata restrict deposition to a 4–5 m.y interval from 61–56 Ma (Idleman *et al*., 2011). Maximum depositional ages from Arkose Ridge Formation sandstones overlap with lava ages from the Eocene phase of magmatism, suggesting deposition of the Arkose Ridge Formation occurred during a well-documented episode of spreading ridge subduction.

Volcanic and sedimentary strata and minor intrusions of the Wrangellia terrane are exposed in south-central and southeastern Alaska and < 40 km north of the Arkose Ridge Formation. The Wrangellia terrane is characterized by Mesozoic isotopic ages primarily from the Middle Jurassic–Early Cretaceous Chitina arc (175–135 Ma) and the Early Cretaceous Chisana arc (155–145 Ma) (Plafker and Berg, 1994). Devonian ages are reported from isolated plutonic rocks and 320–285 Ma ages from the Skolai arc in the Wrangellia terrane (Hampton *et al*, 2007). Assimilation of basement lithologies from the Wrangellia terrane with the Talkeetna magmatic arc is evidenced by inherited Late Carboniferous–Early Triassic zircons in Early Jurassic plutons at the western margin of the Talkeetna magmatic arc (Rioux *et al*., 2007). Two ca. 190 Ma granitoid units parallel and overlap with the Wrangellia terrane contact and are interpreted to represent either early Talkeetna arc magmatism or an unknown part of the Wrangellia crust (Rioux *et al.*, 2007). The Kahiltna assemblage is exposed north of the Wrangellia composite terrane and comprises Upper Jurassic to Upper Cretaceous marine sedimentary strata (Hampton *et al*., 2007). The assemblage is exposed in a ~100 by ~300 km outcrop in the Alaska

Range and a 60 by 150 km outcrop in the northern Talkeetna Mountains. Sedimentary strata consist of mudstone, sandstone, and limestone that yield mainly Mesozoic U-Pb detrital zircon ages (250–100 Ma; 74% of total analyzed grains) with minor Paleozoic (400–300 Ma; 11%) and Precambrian (2.1–1.7 Ga and 3.1–2.5 Ga; 15%) age populations (Hampton *et al*., 2010).

The Upper Cretaceous Matanuska Formation exposed in the Matanuska Valley consists of submarine ramp/slope lithofacies and is characterized by sandstone, conglomerate, and mudstone. Strata were deposited by mass slumps, slides, debris flows, and turbidity currents into the Matanuska Valley-Talkeetna Mountain forearc basin when the Upper Cretaceous–Paleocene magmatic arc was active (Trop, 2008). U-Pb detrital zircon analyses from sandstones in the Matanuska Formation yield ages of 77–71 Ma and granitic clasts in conglomerates from the Matanuska Formation yield ages of 79–77 Ma and imply that the coeval Cretaceous arc plutons were an important source of detritus and unroofed relatively quickly (Trop, 2008). A basin-wide angular unconformity separates Matanuska Formation strata from overlying Arkose Ridge and Chickaloon Formation strata. The presence of the angular unconformity is correlated to tectonic uplift and subaerial exposure of the forearc basin and is consistent with upsection change from marine forearc lithofacies of the Matanuska Formation to the alluvial-fluvial lithofacies of the Arkose Ridge Formation as sediment deposition renewed and the basin subsided again following ridge subduction (Trop, 2008).

Outboard of the forearc basin, marine strata were offscraped, metamorphosed, and accreted into the Chugach accretionary prism exposed about 20–50 km south of the

Arkose Ridge Formation (Fig. 1). The subduction complex contains three fault-bounded belts from north to south that show a systematic southward decrease in age, deformation and metamorphic grade, consistent with northward subduction. From north to south the three distinct belts are: (1) spatially limited Triassic–Jurassic blueschist and late Cretaceous mélange of the McHugh Complex, (2) the latest Cretaceous marine metasedimentary and metavolcanic rocks of the Valdez Group, and (3) the Paleocene–Eocene marine sedimentary and volcanic rocks of the Orca Group (Plafker and Berg, 1994). The Chickaloon Formation at this location is interpreted to be deposited by northward-prograding gravelly alluvial fans and document erosion of the accretionary prism (Little, 1988; Trop *et al.,* 2003), providing evidence for the Matanuska Valley-Talkeetna Mountain as a double-sided forearc basin. Modification of the accretionary prism is documented by near-trench plutons attributable to Paleogene slab-window magmatism (Bradley *et al.,* 2003).

Alluvial-fluvial sedimentary and volcanic strata exposed in the eastern Susitna basin along Willow Creek represent the westernmost Arkose Ridge Formation outcrops (Fig. 4; Winkler, 1992). Previous geochronologic data consists of a single K-Ar age reported to be 56.2 ± 1.7 Ma from a whole-rock analysis using isotope-dilution/mass-spectrometric techniques on one of the interbedded lava flows exposed at Willow Creek (Silberman and Grantz, 1984). This age overlaps with 60–56 Ma isotopic ages of volcanic interbeds from Arkose Ridge Formation strata exposed in the Talkeetna Mountains (Idleman *et al*., 2011). Mafic lavas (Silberman and Grantz, 1984) unconformably overlie granitoid north of Willow Creek, at Willow Bench and Kashwitna

River Bluff (Fig. 3) and yield a 51.8 ± 1.6 Ma K-Ar age. This study presents new geochronologic, sedimentological, and compositional data from the Willow Creek area (including Kashwitna River Bluff and Willow Bench), permitting correlation to Arkose Ridge Formation strata exposed in the southern Talkeetna Mountains and Paleogene volcanic strata in the western and eastern portions of the outcrop belt.

METHODS

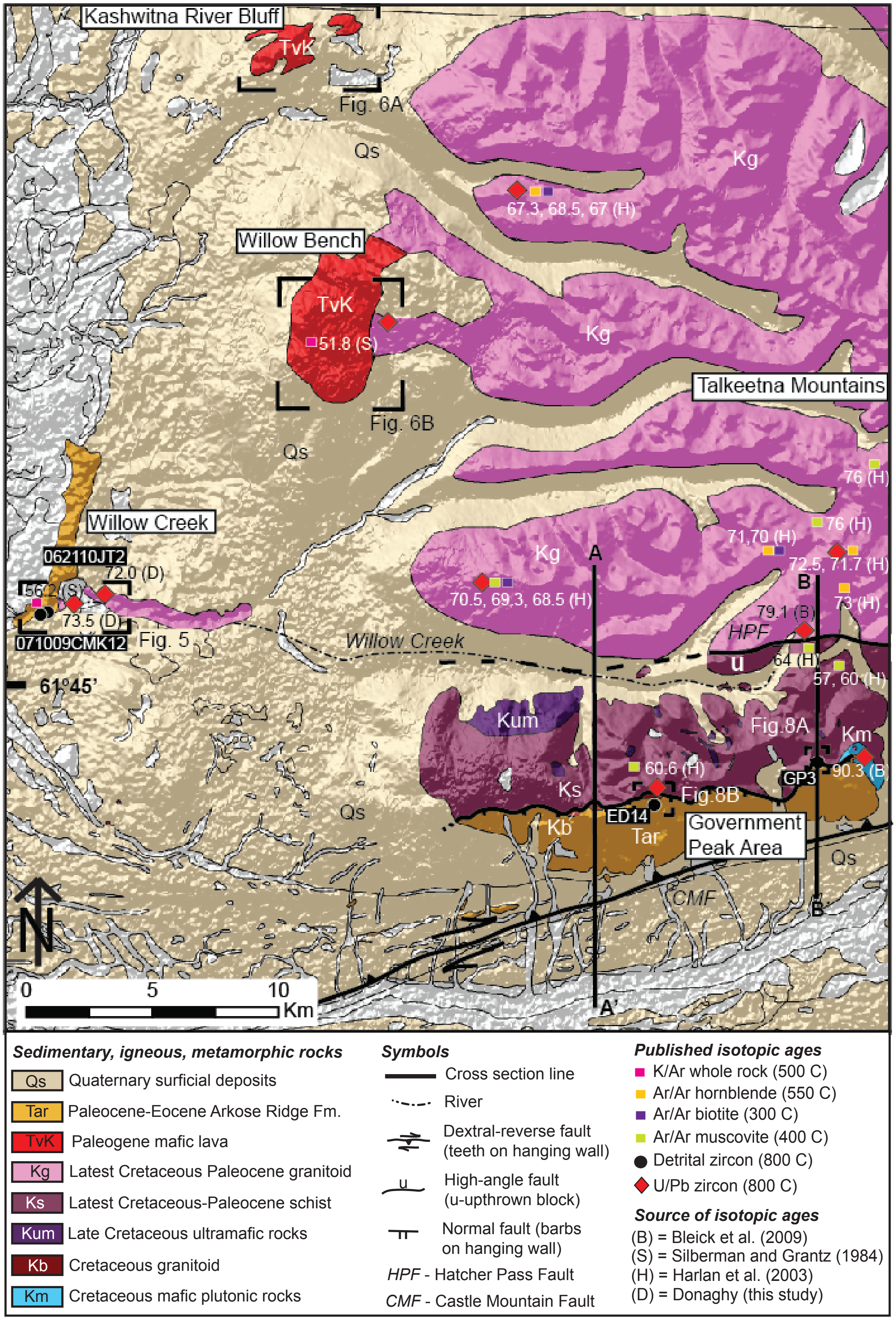
Field Work

Field work in July 2011 consisted of collecting samples for petrographic and geochronologic analyses, measuring bed-by-bed stratigraphic sections, and mapping the geology of the strata exposed along Willow Creek. Reconnaissance mapping and sampling for petrographic and geochronologic analyses was also carried out north of Willow Creek at Willow Bench and Kashwitna River Bluff, as well as east of Willow Creek at Government Peak and Bald Mountain Ridge (Fig. 4).

Field measurements

Stratigraphic sections were measured on a bed-by-bed basis using a Jacob staff. The long axes of the ten largest clasts per conglomerate bed were measured to aid in lithofacies interpretations. See Tables 1 and 2 for maximum particle size data for stratigraphic sections. Bedrock geologic mapping was completed using a Brunton compass, handheld GPS, and aerial photographs to produce a geologic map of the Willow Creek area on a 1:63,360 scale topographic base. The stratigraphy was subdivided into four lithofacies associations that are depicted on the geologic map.

Figure 4. Enlarged generalized geologic map of Willow Creek and the surrounding study areas at Kashwitna River Bluff, Willow Bench, and the Government Peak area in the southwestern Talkeetna Mountains. The geology overlays a digital elevation model (DEM) that shows changes in terrain elevation in the study area. All published isotopic ages and detrital zircon sample locations from previous studies and this study are displayed. The sample location of the K/Ar whole rock analysis (Silberman and Grantz, 1984) of an interbedded lava at Willow Creek is estimated from earlier maps. See Figure 3 for map location.



Kashwitna River Bluff
TvK
Fig. 6A
Qs
Kg
67.3, 68.5, 67 (H)
Willow Bench
TvK
51.8 (S)
Kg
Talkeetna Mountains
Fig. 6B
Qs
76 (H)
76 (H)
71,70 (H)
72.5, 71.7 (H)
73 (H)
Willow Creek
062110JT2
72.0 (D)
56.2 (S)
73.5 (D)
071009CMK12
Fig. 5
Kg
A
70.5, 69.3, 68.5 (H)
B
79.1 (B)
HPF
u
64 (H)
57, 60 (H)
Willow Creek
61°45'
Kum
Fig.8A
Km
60.6 (H)
90.3 (B)
GP3
Ks
Fig.8B
ED14
Kb
Tar
Government
Peak Area
Qs
CMF
B'
0 5 10
Km
A'
Sedimentary, igneous, metamorphic rocks
Qs Quaternary surficial deposits
Tar Paleocene-Eocene Arkose Ridge Fm.
TvK Paleogene mafic lava
Kg Latest Cretaceous Paleocene granitoid
Ks Latest Cretaceous-Paleocene schist
Kum Late Cretaceous ultramafic rocks
Kb Cretaceous granitoid
Km Cretaceous mafic plutonic rocks
Symbols
Cross section line
River
Dextral-reverse fault (teeth on hanging wall)
High-angle fault (u-upthrown block)
Normal fault (barbs on hanging wall)
HPF - Hatcher Pass Fault
CMF - Castle Mountain Fault
Published isotopic ages
K/Ar whole rock (500 C)
Ar/Ar hornblende (550 C)
Ar/Ar biotite (300 C)
Ar/Ar muscovite (400 C)
Detrital zircon (800 C)
U/Pb zircon (800 C)
Source of isotopic ages
(B) = Bleick et al. (2009)
(S) = Silberman and Grantz (1984)
(H) = Harlan et al. (2003)
(D) = Donaghy (this study)

Paleocurrent measurements were made by measuring the orientation of imbricated clasts in pebble-cobble conglomerate using a Brunton compass to measure strike and dip of imbricated planes. These measurements were then converted to the azimuths of paleocurrent direction. Using Stereonet 6.3.3 (Allmendinger, 2006), individual azimuth measurements were structurally restored to horizontal by correcting for the dip of beds and then plotted to create rose diagrams. Ten different clasts were measured in one conglomerate package to ensure statistical significance. See Table 3 for raw and structurally corrected azimuths of paleocurrent measurements.

Field Sampling

Sandstone and granite samples were collected in context of measured stratigraphic sections for geochronological and petrographic analyses. For geochronology analyses, 10–15 kilograms of fist-sized medium-to coarse-grained sandstone samples and granite samples were collected from exposed bedrock. For thin-section petrographic analyses, fist-sized samples of medium-to coarse-grained sandstone were collected. During sampling, attention was given to avoiding faults, veins, and contamination from other rocks and soil.

Conglomerate Clast Counts

A total of seven conglomerate clast counts were obtained in the field in context of the measured sections. For each count, the lithology of at least 100 different clasts were identified in a randomly chosen ~1–2 by ~1–2 meter surface on a single bed of conglomerate. A minimum population of 100 individual clasts per bed was used to ensure statistical significance. See Table 4 for raw clast count data and recalculated detrital modes for each sample location.

Sandstone Petrography

Standard petrographic thin sections were made from four medium- to coarse-grained sandstones that were collected within the context of two measured stratigraphic sections. One half of each thin section was stained for plagioclase and potassium feldspar. Thin sections were examined to determine populations of common mineral grains and rock fragments present within the sandstone lithofacies as well as the degree of rounding, sorting, and matrix content. Photomicrographs of representative minerals from each population were taken using a polarizing microscope.

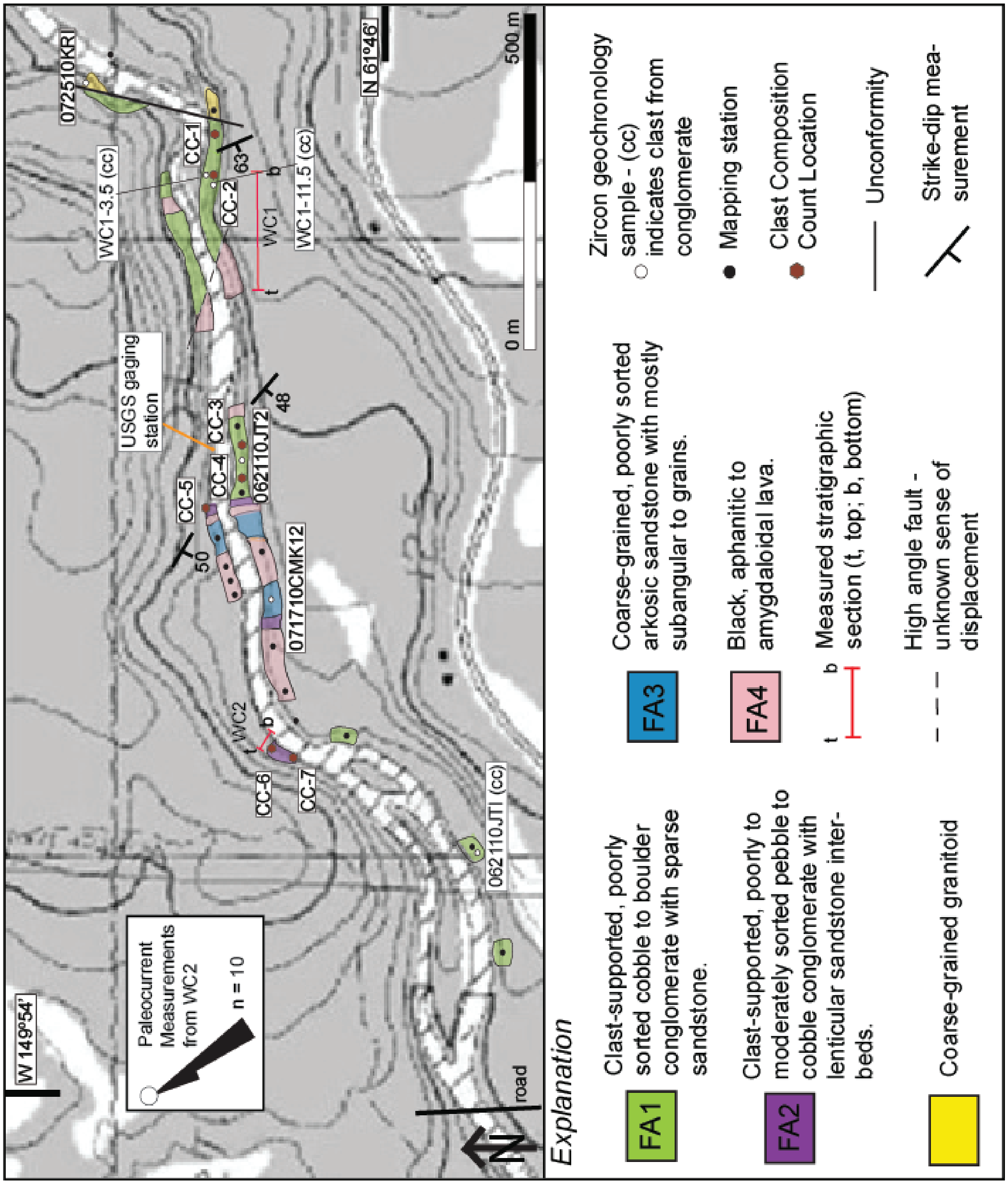
Geochronology Analyses

A total of two detrital sandstone samples and two granite samples were analyzed for geochronology. Using a jaw crusher, fist-sized rock samples were crushed to granule and finer grained particles. This material was then pulverized to sand and finer grained particles using a disc mill. The pulverizing process was completed in numerous steps of progressively moving the discs closer together and sieving the sample between each step to maximize the yield of monocrystalline zircon grains. All samples produced ~6–8 kilograms of pulverized sand and silt. Samples were then taken to Lehigh University where zircon grains were separated using a Wilfley table, Franz magnetic separator, and a heavy liquid density separation technique using methylene iodide. Each sample yielded hundreds of zircon grains. Sample unknowns and standards were mounted together in a 1" diameter round epoxy plug and polished to half thickness. To help guide in spot analyses, photomicrographs were taken of all mounted zircon grains.

Isotopic analyses were conducted at the University of Arizona's Laserchron Center using a laser-ablation-inductively-coupled-plasma-mass-spectrometer (LA-ICP-MS) using the methods outlined by Gehrels (2012). To collect analyses reflecting the true distribution of ages of the sample, zircon grains were randomly selected by different color, morphology, and size (Gehrels, 2012). Zircons with cracks and inclusions were avoided to decrease errors in calculated ages due to Pb loss in the grain along fractures. Before each new sample, a Sri Lanka standard (SL; 563.5 ± 2.3 Ma; Gehrels *et al.*, 2008) was measured five times and a R33 standard (419.3 ± 0.4 Ma) was measured twice to calibrate the LA-ICP-MS. Each zircon grain was ablated using a Photon Machines Analyte G2 excimer laser equipped with a HelEX low-volume cell and a laser spot diameter of 10–35 microns. The laser beam was centered on the core of the grains to avoid alteration due to metamorphism. The ablated material was then carried by helium gas into the plasma source of a multicollector inductively coupled plasma mass spectrometer (Gehrels *et al.,* 2006). The flight tube of the isoprobe is of adequate width such that the ^{278}U, ^{235}U, ^{206}Pb, ^{207}Pb, and Th isotopes are measured simultaneously for each spot analysis (Gehrels *et al.,* 2006). At minimum, 100 zircon grains from each sandstone detrital sample were randomly selected for isotopic analyses to identify the main age populations present. Analyses were calibrated against a Sri Lanka standard (563.5 ± 2.3 Ma; Gehrels *et al.,* 2008) after every five measurements of an unknown zircon grain. For igneous samples, a minimum of 30–40 zircon grains from each sample were selected. Analyses were calibrated against the Sri Lanka standard (SL; Gehrels *et al.*, 2008) after every three measurements of an unknown zircon grain. The R33 standard was also measured three times at the end of each sample for both detrital and igneous analyses.

The $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ratios and apparent ages were then calculated using the Isoplot software (Ludwig, 2003). All systematic errors, including calibration of the standard, the age of the calibration standard, and measurement errors of the U-Pb ages, are 1–2% (Gehrels *et al.*, 2008). The data were filtered according to precision (10% cutoff) and discordance (30% cutoff) and plotted on age probability and U-Pb Concordia plots (Ludwig, 2003). The relative age probability plots were constructed by calculating a normal distribution for each analysis based on the reported age and uncertainty and then summing the probability distributions of all accepted analyses into a single curve (Gehrels *et al.*, 2006). Zircons grains are subject to Pb loss/inheritance and metamorphic alterations, which causes analyses to scatter from their true U-Pb age. It is unlikely that three or more grains will experience the same Pb loss/inheritance and yield the same age, thus clustering of U-Pb ages was used to determine significant ages and for calculations of the maximum depositional age (Dickinson and Gehrels, 2009). U/Th ages were plotted to help distinguish the detrital sandstone grains derived from metamorphic versus igneous/sedimentary sources.

Figure 5. Geologic map of Willow Creek area showing poorly sorted boulder conglomerate (FA1), moderately sorted cobble conglomerate (FA2), sandstone (FA3), and lavas (FA4) that unconformably overlie Cretaceous granitoid. See text for detailed description of each facies association. CC-X represents locations of clast composition counts. Rose diagram in upper left represents paleocurrent flow direction. Measurements were taken from imbricated clasts in FA2 conglomerate (n = number of clasts measured).


W 149°54'
Paleocurrent Measurements from WC2
n = 10
road
N
072510KRI
WC1-3.5 (cc)
CC-1
63
CC-2
WC1-11.5 (cc)
WC1
t
b
USGS gaging station
48
CC-3
CC-4
062110JT2
CC-5
50
071710CMK12
WC2
CC-6
CC-7
062110JTI (cc)
N 61°46'
0 m
500 m
Explanation
FA1
Clast-supported, poorly sorted cobble to boulder conglomerate with sparse sandstone.
FA2
Clast-supported, poorly to moderately sorted pebble to cobble conglomerate with lenticular sandstone inter-beds.
Coarse-grained granitoid
FA3
Coarse-grained, poorly sorted arkosic sandstone with mostly subangular to grains.
FA4
Black, aphanitic to amygdaloidal lava.
Measured stratigraphic section (t, top; b, bottom)
High angle fault - unknown sense of displacement
Zircon geochronology sample - (cc) indicates clast from conglomerate
Mapping station
Clast Composition Count Location
Unconformity
Strike-dip mea-surement

NEW GEOLOGIC MAPPING

New geologic mapping from this study documents the nature of Arkose Ridge Formation strata exposed at Willow Creek at a 1:63,360 scale and lavas that crop out nearby at Kashwitna River Bluff and Willow Bench, north of the Willow Creek study area (Fig. 4). This is the first study to map the Arkose Ridge Formation at Willow Creek at a 1:63,360 scale and to split out distinct lithofacies associations (Fig. 5). Sedimentary and volcanic strata mapped as Arkose Ridge Formation crop out in well exposed, approximately ten-meter-tall cliffs, along river cuts of Willow Creek. Although strata are well exposed along the stream, access to outcrops is limited by stream stage as well as by thick brush/woods and by the steep relief of river cuts along the stream. Because of these variables, the overall nature of the section consists of intermittent well-exposed sedimentary and volcanic strata separated by covered intervals. The strata become increasingly more poorly exposed with distance from the stream channel, largely due to thick brush coverage and a lack of a mechanism (i.e. streamflow of Willow Creek) to expose the underlying rocks. Outcrops cut by the river generally exhibit strata dipping between 48° and 63° to the southwest. The total measured section of the Arkose Ridge Formation at Willow Creek is approximately 467 meters thick. The contact between Arkose Ridge Formation strata and the underlying granitoid is covered by vegetation at Willow Creek. The lack of faults and other strain features in lowermost sedimentary strata above the contact support a nonconformable contact between the strata and the underlying granitoid. Previous research documents the depositional relationship of Arkose Ridge Formation strata directly overlying the granitoid at other localities in the southern Talkeetna Mountains, where the contact is directly observable (Kassab *et al*., 2009; Kortyna *et al*., 2009). Uppermost strata of the Arkose Ridge Formation has been eroded along Willow Creek.

Reconnaissance mapping of foothills located northeast of Willow Creek along the west flank of the Talkeetna Mountains documents tens-of meters thick packages of black, aphanitic lavas. The lavas are best exposed along the crest of two hilltops with USGS benchmarks (BENCH and KASH on Fig. 6) that informally referred to here as Willow Bench and Kashwitna River Bluff. Outcrop are limited to <100m^2 outcrops and contact relations with the underlying granitoid cannot be directly observed. The contact is interpreted to be an unconformity based on the flat-lying orientation of bedding in the lavas together with the topographic position of lavas above the granitoid. Figure 7 shows photographs of the contact relationship and characteristics of the Willow Bench lavas. The mineralogy and texture of the lavas are comparable to the thick-bedded lavas exposed at Willow Creek. Ongoing petrographic, geochemical, and geochronological analyses will help evaluate the possible relationships between the sampled lavas at Willow Creek, Willow Bench, and Kashwitna River Bluff. Willow Bench and Kashwitna River Bluff were previously mapped as Arkose Ridge Formation (Winkler, 1992), but the mafic lava flows have been subdivided as a new unit, Tvk on Figure 4 in the context of this study. Although a lava lithofacies is associated with the Arkose Ridge Formation, the complete absence of other alluvial-fluvial lithofacies of Arkose Ridge Formation led the Tvk unit to be distinguished as separate from the Arkose Ridge Formation deposits at Willow Bench and the Kashwitna River Bluff.

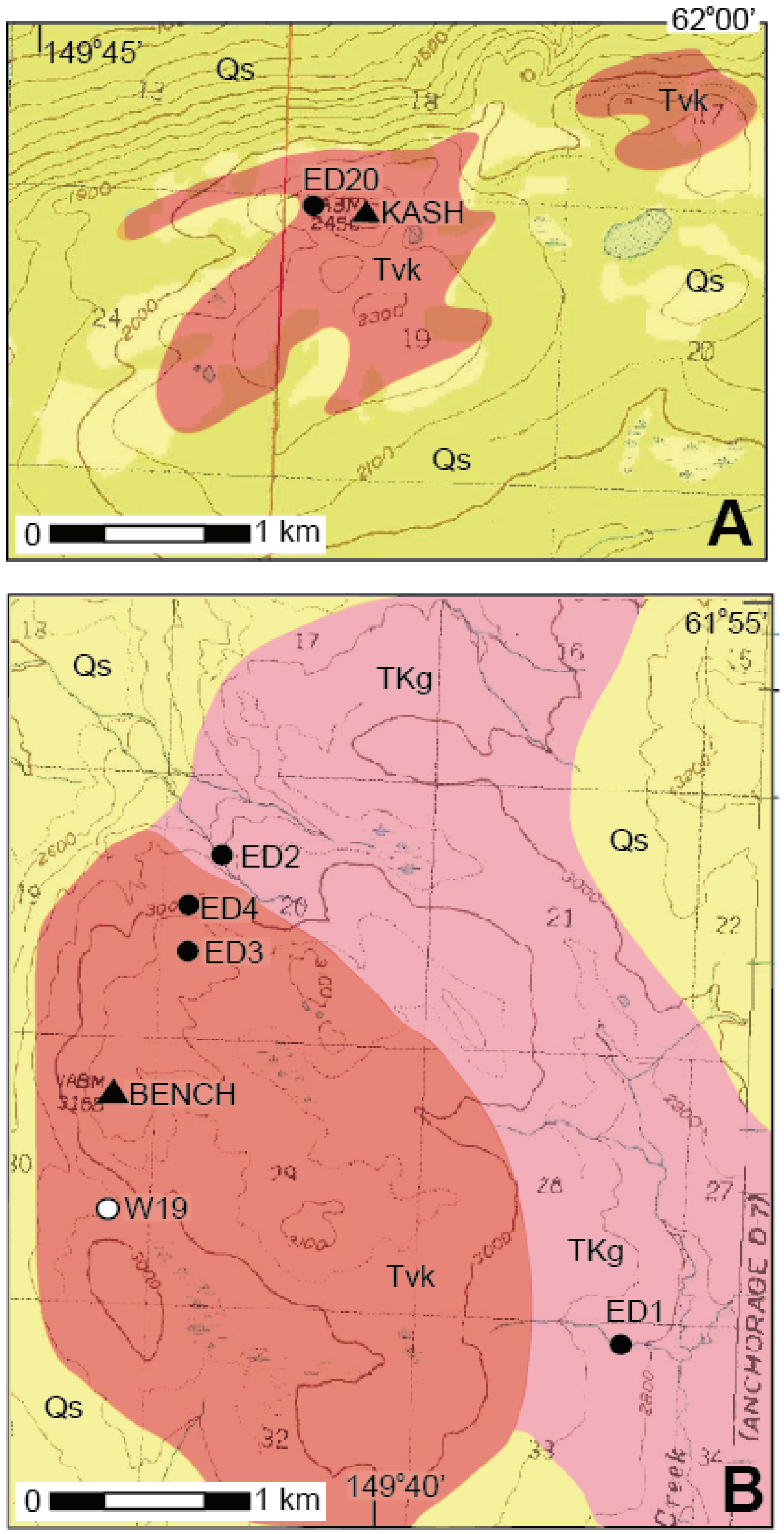
New geologic mapping at a 1:63,360 scale in the Government Peak area documents discontinuous tens-of-meters thick exposures of granular- to medium-grained arkosic sandstone with thin interbeds of pebble conglomerate and black, aphanitic to vesicular basalt. These strata are correlated to the Arkose Ridge Formation and unconformably overlie a granitoid pluton locally (Fig. 8). Although the contact is not well-exposed at this location, Arkose Ridge Formation strata appear to unconformably overlie the granitoid pluton. Direct evidence for fault-related deformation such as slickenlines or fault breccia was not observed in either unit along the contact. Previous mapping documented discontinuous exposures of previously undated granitoid along the Bald Mountain Ridge that was tentatively assigned a Jurassic age (Winkler, 1992). New U-Pb zircon ages obtained from the granitoid demonstrate a Late Cretaceous emplacement age (discussed below). See Figure 9 for representative photographs of the Government Peak study area.

SEDIMENTOLOGIC DATA

Sedimentary and Volcanic Lithofacies Associations

The Arkose Ridge Formation exposed at Willow Creek consists of conglomerate, sandstone, and lava approximately 467 m thick (Fig. 10). New geologic mapping of the Willow Creek area (Fig. 5), detailed bed-by-bed measurements of two stratigraphic sections (Fig. 11), paleocurrent measurements, and particle size data document four lithofacies associations. Paleocurrent data were measured from ten imbricated clasts (Table 3) in one conglomerate bed at one location within the WC2 stratigraphic section.

Figure 6. Reconnaissance geologic map of the (A) Kashwitna River Bluff (KASH) and (B) Willow Bench area (BENCH) showing newly mapped lavas (Tvk) attributed to proximal fissure eruptions. Black circles denote locations of collected lava samples for this study, white circles denote location for geochronology samples reported by Silberman and Grantz (1984), black triangles represent U.S.G.S. benchmarks. Abbreviations: TKg - Latest Cretaceous-Paleocene granitoid pluton; Qs - Quaternary surficial deposits; Tvk - Paleogene mafic volcanic lavas. See Figure 4 for map location. Modified from Winkler (1992).


62°00'
149°45'
Qs
Tvk
ED20
KASH
Tvk
Qs
Qs
0
1 km
A
61°55'
Qs
TKg
Qs
ED2
ED4
ED3
BENCH
W19
Tvk
TKg
ED1
Qs
149°40'
0
1 km
B

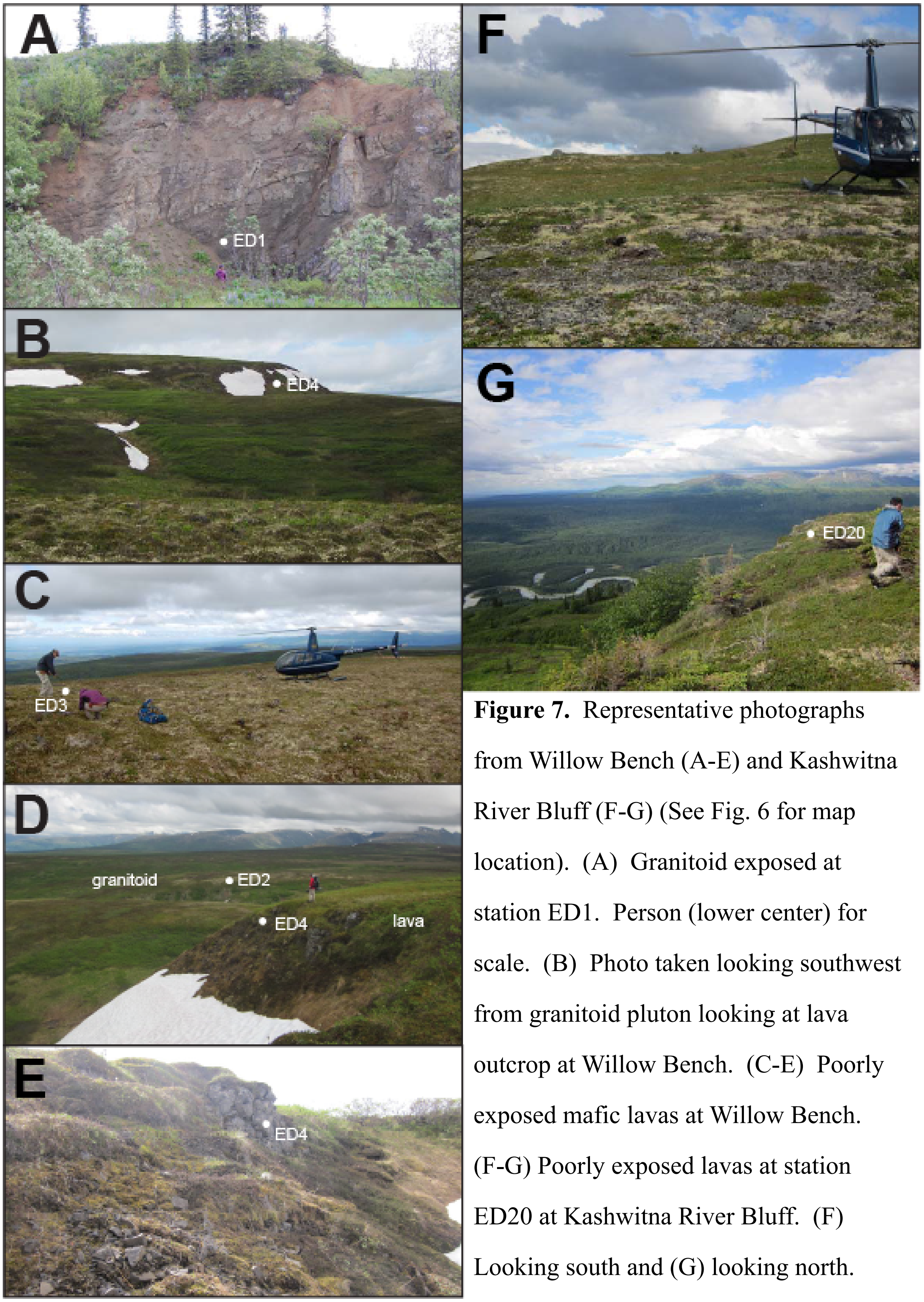
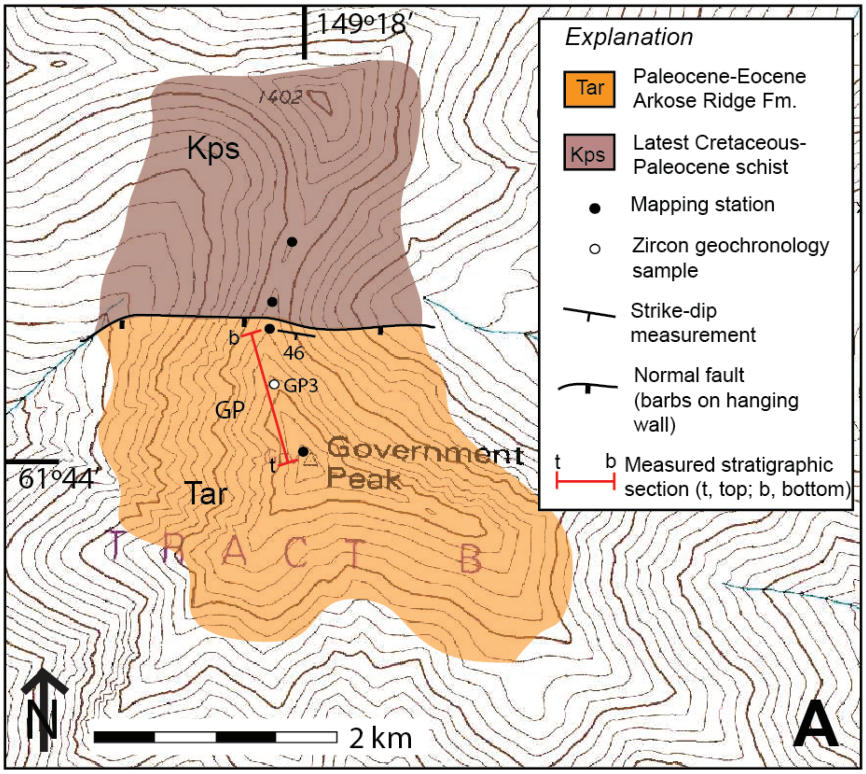
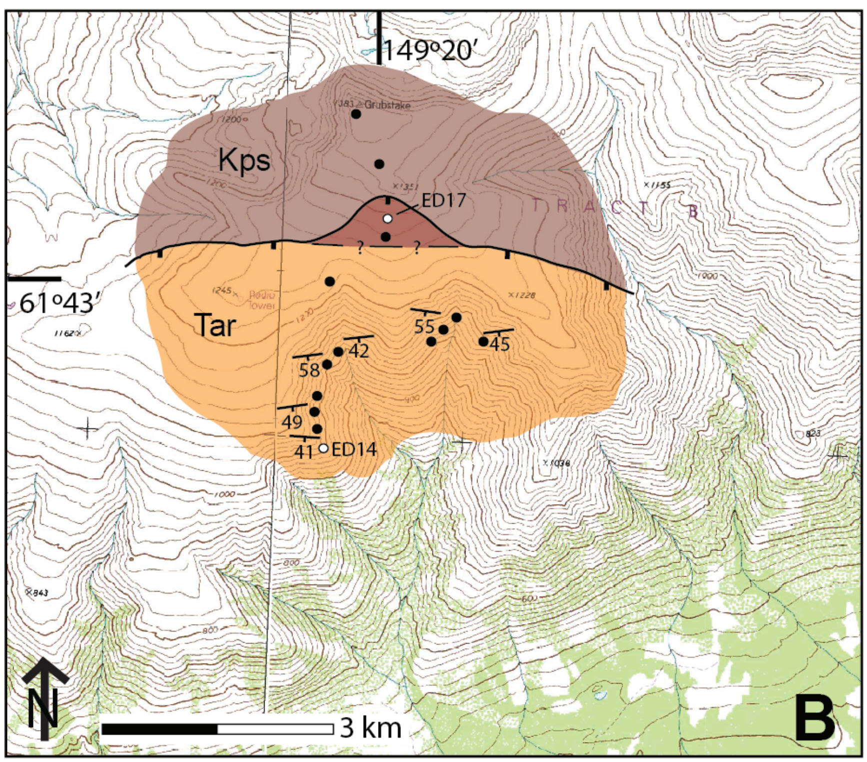


Figure 7. Representative photographs from Willow Bench (A-E) and Kashwitna River Bluff (F-G) (See Fig. 6 for map location). (A) Granitoid exposed at station ED1. Person (lower center) for scale. (B) Photo taken looking southwest from granitoid pluton looking at lava outcrop at Willow Bench. (C-E) Poorly exposed mafic lavas at Willow Bench. (F-G) Poorly exposed lavas at station ED20 at Kashwitna River Bluff. (F) Looking south and (G) looking north.

Figure 8. Reconnaissance geologic maps of Government Peak area, including (A) Government Peak and (B) Bald Mountain Ridge. New mapping data indicates the contact between the Arkose Ridge Formation (Tar) and the Hatcher Pass schist (Kps) is a low-angle normal fault at both Government Peak and Bald Mountain Ridge, consistent with mapping by Bleick *et al* (2009). New mapping at Bald Mountain Ridge documents Arkose Ridge Formation strata overlying a discontinuous exposure of granitoid along an unconformity. The Arkose Ridge Formation and pluton are faulted against the Hatcher Pass schist. Note that only the new geologic mapping from this study is displayed on the maps and to see Figure 4 for the entire Government Peak area. See Figure 28 for the detailed measured stratigraphic section of Arkose Ridge Formation strata at Government Peak (GP). Modified from Winkler (1992).


149°18′
Explanation
Tar
Paleocene-Eocene Arkose Ridge Fm.
Kps
Latest Cretaceous-Paleocene schist
Mapping station
Zircon geochronology sample
Strike-dip measurement
Normal fault (barbs on hanging wall)
t b
Measured stratigraphic section (t, top; b, bottom)
1402
Kps
b
46
GP3
GP
t
Government Peak
61°44′
Tar
T R A C T B
N
2 km
A


149°20′
Kps
ED17
?
?
61°43′
Tar
55
45
42
58
49
41
ED14
N
3 km
B

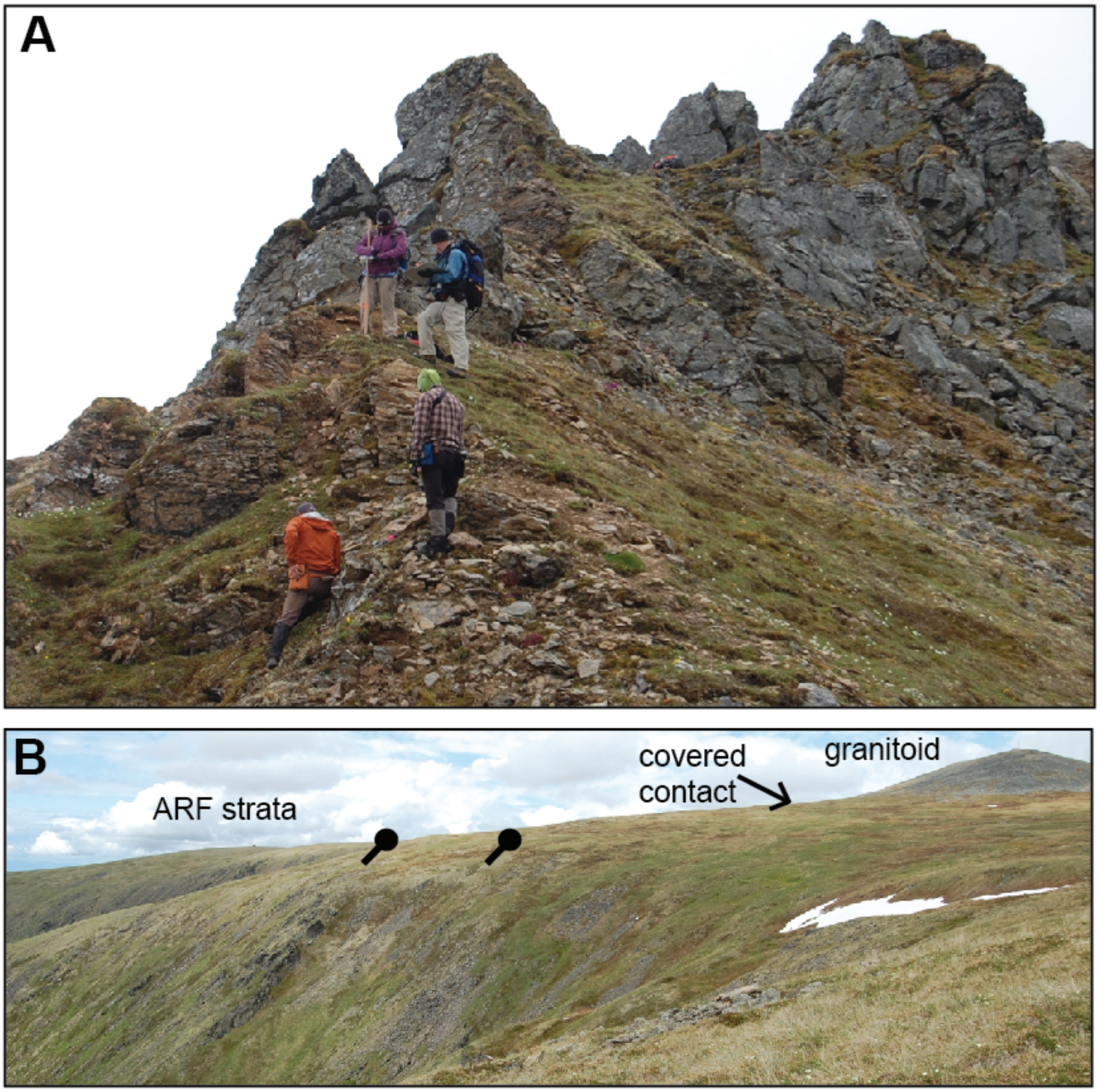


Figure 9. Representative photographs from (A) Government Peak and (B) Bald Mountain Ridge in the Government Peak Area (See Fig. 8 for map location). (A) Arkose Ridge Formation sandstone and minor interbeds of conglomerate (above people) exposed in a 120 meter thick section normal faulted against the Hatcher Pass schist. People are studying in the fault zone. Photo taken looking south towards Government Peak. (B) Photo taken looking west along Bald Mountain Ridge with south-dipping Arkose Ridge Formation (ARF) sandstones (left) unconformably overlying discontinuous exposures of granitoid (right). Black tadpole symbol indicates dip of bedding (left in photo).

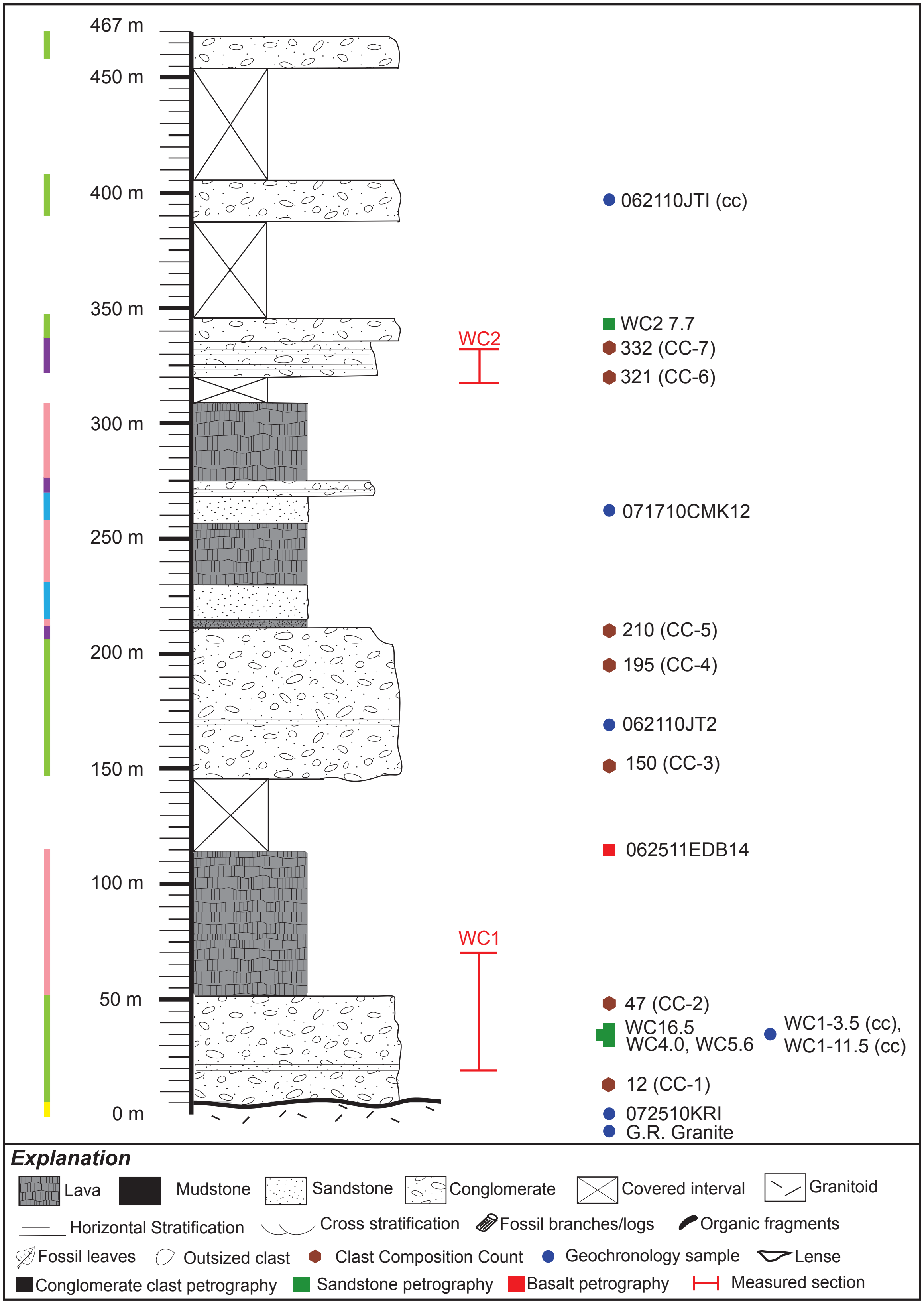
Maximum particle size (MPS) data were obtained from 28 conglomerate beds at 5 locations, totaling 310 measurements (Tables 1 and 2). Sedimentology and inferred depositional environments of lithofacies associations were determined by differences in grain size and sorting, composition, geometry and thickness of bedding, and types of sedimentary structures present. Four lithofacies associations characterize the stratigraphy and represent deposition by debris flow/hyperconcentrated flow, stream flow, and effusive volcanic eruptions on a high-gradient, braided stream system. Each lithofacies association is described and interpreted below.

Lithofacies Association 1: Cobble-Boulder Conglomerate

Description

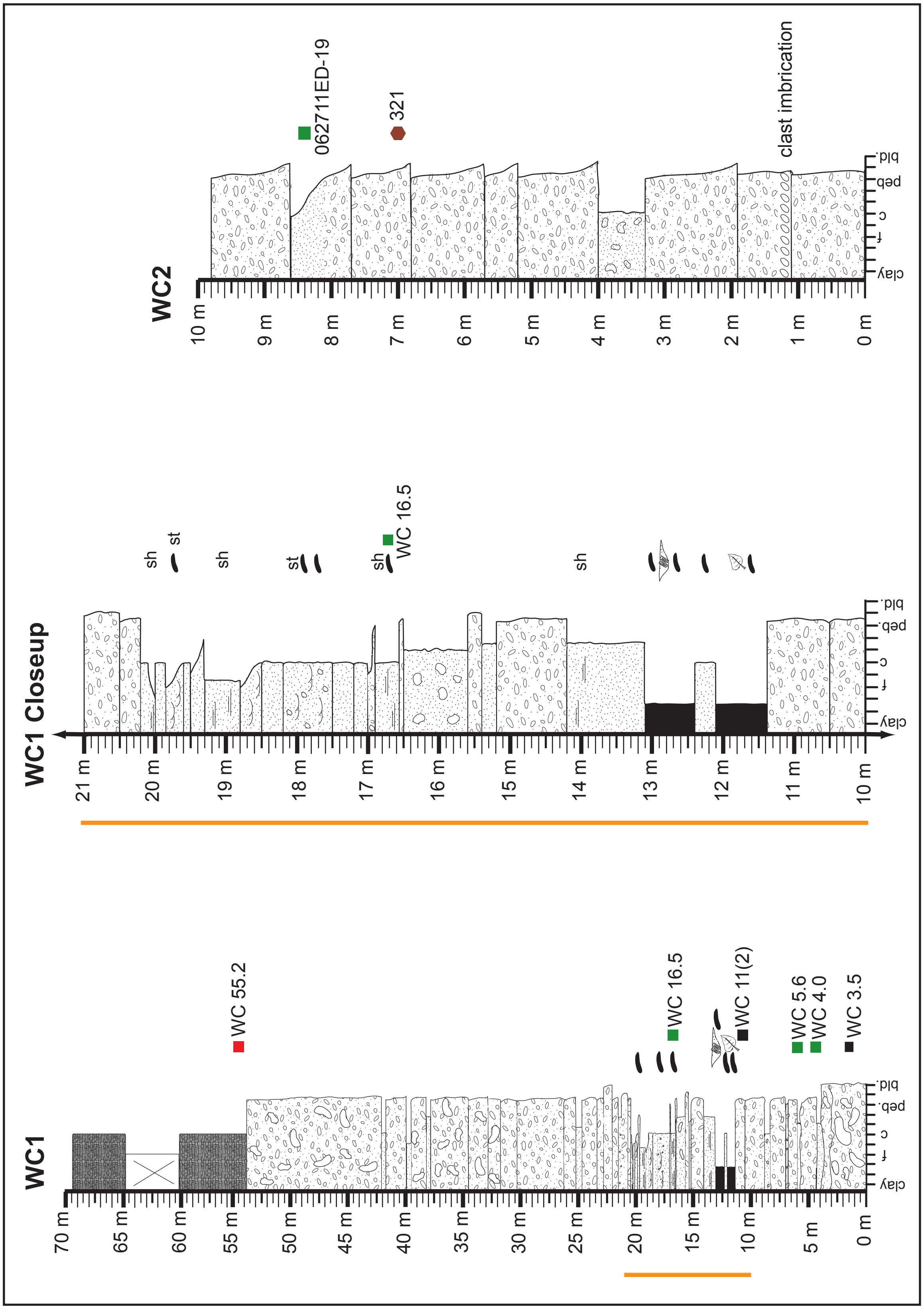
Conglomerate beds of lithofacies association 1 (FA1) characterize the lower and uppermost sections of exposed strata and represent approximately 45% of the total thickness of strata exposed along Willow Creek (Fig. 10). The lowermost exposure of FA1 conglomerate in the generalized section of Willow Creek unconformably overlies the westernmost exposures of Cretaceous granitoid of the Willow Pluton (Fig. 12). FA1 consists of clast- to matrix-supported, poorly sorted, massive cobble-boulder conglomerate with maximum preserved thickness of individual packages up to 105 m thick (Fig. 11). MPS data collected at four locations in FA1 were measured in 20 separate conglomerate beds for a total of 200 measurements (Table 1). Clasts are subrounded to rounded and dominantly cobble-size, although boulder-size clasts up to 80 cm in conglomerate beds are exposed in the uppermost section of exposed FA1 (Fig. 13).

Figure 10. Generalized stratigraphic section showing poorly sorted boulder conglomerate (FA1; 45% of exposed strata), moderately sorted cobble conglomerate (FA2; 9%), sandstone (FA3; 8%), and lavas (FA4; 38%) that unconformably overlie a Cretaceous aged granitoid. Covered intervals represent 131 m (28% of total measured section) of the total 467 m measured section. The color bars to the left of the measured section represent the map colors of each facies association, shown on the geologic map in Figure 5, and show stratigraphic position of different associations along Willow Creek. Red vertical bars represent stratigraphic position of measured sections WC1 and WC2 shown in Figure 5. Colored symbols denote stratigraphic position of petrography samples, clast composition counts, and geochronology samples in measured section. The labels for the clast composition locations represent the stratigraphic position of the sample in meters and CC-X refers to sample location on geologic map of Willow Creek (Fig. 5). The abbreviation (cc) for geochronologic samples indicates sample is a clast from conglomerate.



467 m
450 m
400 m
350 m
300 m
250 m
200 m
150 m
100 m
50 m
0 m
WC2
WC1
062110JTI (cc)
WC2 7.7
332 (CC-7)
321 (CC-6)
071710CMK12
210 (CC-5)
195 (CC-4)
062110JT2
150 (CC-3)
062511EDB14
47 (CC-2)
WC16.5
WC4.0, WC5.6
WC1-3.5 (cc),
WC1-11.5 (cc)
12 (CC-1)
072510KRI
G.R. Granite
Explanation
Lava
Mudstone
Sandstone
Conglomerate
Covered interval
Granitoid
Horizontal Stratification
Cross stratification
Fossil branches/logs
Organic fragments
Fossil leaves
Outsized clast
Clast Composition Count
Geochronology sample
Lense
Conglomerate clast petrography
Sandstone petrography
Basalt petrography
Measured section

Figure 11. Bed-by-bed measured stratigraphic sections of strata exposed along Willow Creek. Massive, meter-thick amalgamated packages of conglomerate are characterized by scoured bases and outsized clasts in WC1 and WC2. Section WC1 shows lowermost strata, including interbedded poorly sorted boulder conglomerate (FA1) and lavas (FA4). Sandstone to mudstone intervals are shown in more detail in WC1 Closeup. The orange bar to left of WC1 denotes section defined in WC1 Closeup. Massive, meter-thick packages of pebble-cobble conglomerate with interbeds of organic rich mudstone and sandstone compose the finer-grained interval within FA1. Lenticular sandstone beds are horizontally stratified to cross-stratified, contain pebble to cobble outsized clasts, and commonly exhibit well-developed fining upward sequences. The mudstone interval is composed of fine-grained sandstone to siltstone and contains abundant coalified stringers and lenses of carbonaceous material including stems and small logs. Section WC2 shows middle-upper part of section, chiefly moderately sorted cobble conglomerate (FA2) with well-developed upward fining sequences and clast imbrication. See Figure 5 for map showing section locations. Sample labels indicate the stratigraphic position in meters in the generalized section of Willow Creek (Fig. 10). The (cc) abbreviation for geochronologic samples indicates sample is a clast from conglomerate. See Figure 10 for explanation of symbols. Grain size unit abbreviations: f = fine; c = coarse; peb. = pebble; bld = boulder.


WC1
70 m
65 m
60 m
55 m
50 m
45 m
40 m
35 m
30 m
25 m
20 m
15 m
10 m
5 m
0 m
clay
f
c
peb.
bld.
WC 55.2
WC 16.5
WC 11(2)
WC 5.6
WC 4.0
WC 3.5
WC1 Closeup
21 m
20 m
19 m
18 m
17 m
16 m
15 m
14 m
13 m
12 m
11 m
10 m
sh
st
sh
st
sh
WC 16.5
sh
WC2
10 m
9 m
8 m
7 m
6 m
5 m
4 m
3 m
2 m
1 m
0 m
062711ED-19
321
clast imbrication

The coarse-grained, arkosic sandstone matrix is moderately to poorly sorted with angular to subangular grains. Coarse-grained sandstone interbeds, up to 1.5 m thick, are compositionally identical to the conglomerate matrix. These lenticular bedded sandstones contain high abundances of fragmented and disseminated organic material and are discontinuous over lateral distances less than 5 m. Organic-rich mudstones are interbedded with the sandstone; together the sandstone and mudstone makes up less than 5% of FA1. Measured section WC1 (Fig. 11) summarizes sedimentary structures and bed geometries in conglomerates and sandstones of FA1. Figure 13 and Figure 14 show representative photographs of sedimentary structures and characteristics of FA1.

Interpretation

Conglomerates and minor sandstones of FA1 document deposition by both high-energy streamflow and debris/hyperconcentrated flows in gravelly braided channels on a steep-gradient alluvial slope. Poorly-sorted, matrix- to clast-supported conglomerates and minor coarse-grained sandstones record deposition by debris- and stream-flow on the proximal reach of alluvial slope. Massive, amalgamated packages of the matrix-supported conglomerate component of FA1 (Fig. 14) are consistent with deposition in a single flow as one mass by debris flows and hyperconcentrated flood flows (Pierson, 1980; Smith 1986). Scours at the base of these packages are erosive contacts that distinguish separate debris-flow events. Rounded to subrounded clasts suspended within a coarse-grained matrix display a largely disorganized and random fabric, further supporting deposition by a cohesive mass flow (Nemec and Postma, 1993).

Clast-supported conglomerates and lenticular sandstones in FA1 record water-lain bedload deposits within broad gravelly channels on the high-gradient, proximal reach of the alluvial slope (Fig. 13C). The lenticular sandstone beds supports lower energy streamflow deposition by migrating sandy channels and bars in the braided stream system. Fining upward sequences, trough cross-bedding and horizontal stratification, and pebble-cobble lags (Fig. 11) are consistent with streamflow deposition by a braided stream system (Prothero and Schwab, 2004). High abundance of organic material in sandstone suggests deposition in a humid, vegetated environment. The highly fragmented and disseminated nature of organic material further supports the high energy of bedload deposition areas. Mudstones in the finer-grained interval, documented in measured section WC1 Closeup (Fig. 11), record overbank and waning-flood deposits which coincide with transportation mainly by flood flow on the proximal alluvial slope. Poorly sorted, angular to subangular grains and the arkosic composition of the sandstone and conglomerate matrix supports the sandstone being compositionally and texturally immature and deposited close to the source. Clast-supported conglomerates and minor sandstone beds indicate transport by a braided fluvial system, but the abundance of poorly sorted, unorganized boulder conglomerate suggest it was influenced by episodic debris flows/hyperconcentrated flows on the proximal reach of an alluvial slope. The lack of fining upward sequences, upsection transitions to fine-grained fluvial-lacustrine strata, and overall poor sorting indicate a proximal alluvial fan system versus deposition on a distal alluvial fan or alluvial plain.

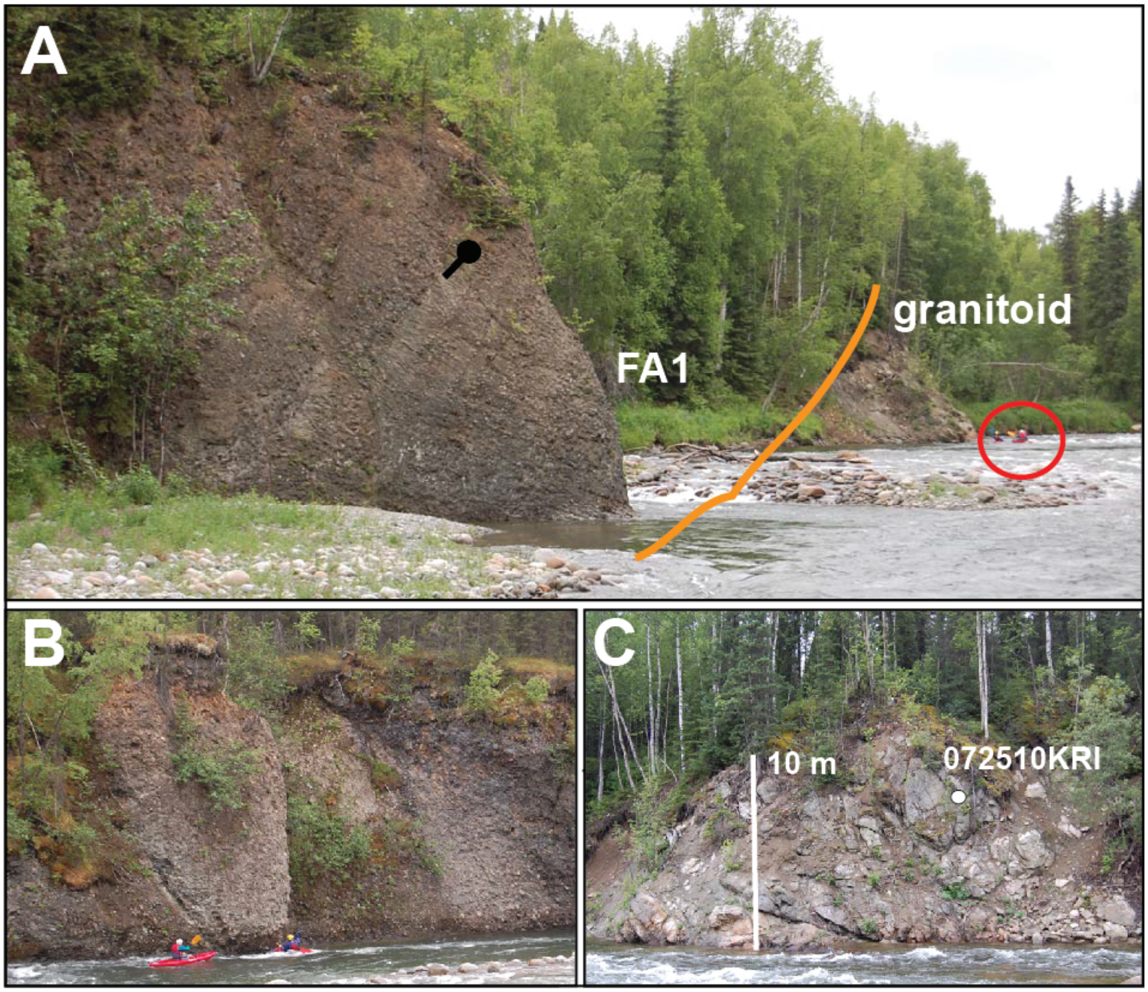


Figure 12. Representative photographs of the Cretaceous granitoid and overlying strata. (A) Image shows inferred position of unconformity location (orange line) between FA1 strata and the underlying granitoid. The lack of faults and offset clasts within the lowermost strata of FA1 is consistent with a depositional contact. Black tadpole symbol indicates dip of bedding (left in photo) and kayakers (circled in red) for scale. (B) Photo shows massive bedding in cobble-boulder conglomerate of FA1 directly above the basal unconformity. Note kayakers for scale in lower left of the photo. (C) Representative photo of the fractured underlying granitoid. Note that sample 072510KRI was collected at this location for U-Pb geochronological analyses.

Figure 13. Representative photographs of the poorly sorted, cobble-boulder conglomerate of FA1 documented at the Willow Creek (A) Poorly sorted, matrix-supported conglomerate. Note hammer in lower right for scale. (B) Clast-supported interbed of FA1 interpreted to be deposited by stream-flow processes on a steep alluvial slope. Note moderately sorted, rounded to subrounded clasts, disorganized fabric, and lack of sedimentary structures. (C) Sandstone interbed (lower left) diagnostic of the finer-grained interbeds within FA1. (D) Matrix-supported conglomerate interbed characteristic of debris/hyperconcentrated flow deposits. Large clast in center of photo above person is 80 cm.

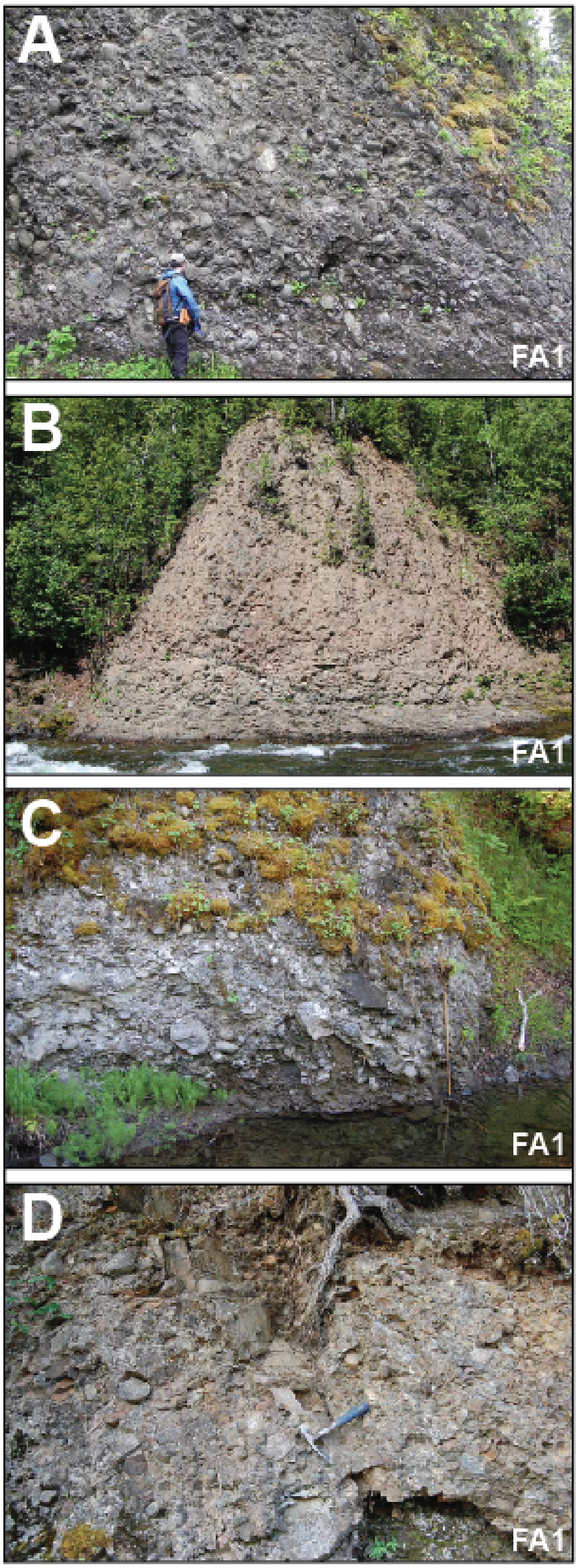


Figure 14. Representative photographs of the poorly sorted, cobble-boulder conglomerate of FA1 documented at the Willow Creek. (A-B) Shows representative photos of FA1 conglomerate. Note lack of organization and sedimentary structures in tens-of-meters thick packages of conglomerate. (C) Poorly sorted, matrix-supported conglomerate interbed characteristic of debris/hyperconcetrated flow. Note multiple large boulder-sized clasts. 1.5 meter tall jacob staff (lower right) for scale. (D) Minor sandstone interbedded within a conglomerate package in FA1. Sandstone interbed (abover hammer and left of root) supports lower energy stream flow deposition by laterally migrating sandy channels and bars in braided stream system. Note hammer for scale directly on top of sandstone channel.

Lithofacies Association 2: Pebble-Cobble Conglomerate

Description

Lithofacies association 2 (FA2) consists of clast-supported, pebble-cobble conglomerate with subordinate lenticular sandstone beds and represents approximately 9% of the total thickness of strata exposed along Willow Creek. The moderately to poorly sorted conglomerate, with maximum preserved thickness of individual packages up to 15 m thick, is exclusively exposed in intervals from 275 m to 345 m in the section along Willow Creek (Fig. 10). Rounded to subrounded clasts are encased in arkosic, coarse- to medium-grained sandstone matrix that is compositionally and texturally consistent with lenticular sandstone interbeds. Sandstone interbeds commonly include minor, interbedded lenses of pebble conglomerate. FA2 is characterized by fining upward sequences 1–2 m thick, clast imbrication, and a high percentage of disseminated, fragmented organic debris. The organic material appears to be fragmented plant stems and leaves, but delicately preserved fossils were not discovered, preventing taxonomic identification. MPS data collected at one location in FA2 were measured in eight separate conglomerate beds for a total of 110 measurements (Table 2). Measurements were made at the top and bottom of conglomerate beds characterized by fining upward sequences. Measured section WC2 (Fig. 11) summarizes sedimentary structures and bed geometries of FA2. Figure 15 shows representative photographs of sedimentary structures and characteristics of FA2.

Interpretation

The overall better organization of the finer-grained conglomerates and the higher percentage of sandstones exposed within FA2 indicate deposition by stream flow on a braided-stream dominated alluvial slope. FA1 and FA2 are lithologically similar but differ in grain size, sorting, and percentages of conglomerate versus sandstone. Both associations are interpreted to be deposited on a proximal, vegetated humid alluvial fan but FA2 consists of finer grained conglomerate with higher degrees of clast rounding and sorting and an overall higher percentage of sandstone.

The high percentage of moderately to poorly sorted conglomerate within FA2 represents waterlain bedload deposition on gravelly longitudinal bars in a braided stream system as a result of high sediment flux in a proximal depositional setting. The trough cross-bedded, lenticular bedded sandstones, with interbedded pebble conglomerate lenses deposited in gravel-pebble lags, were formed by channel cut-and-fill across the alluvial slope in this system (Fig. 15B). Clast imbrication at the base of measured section WC2 were measured as a paleocurrent indicator (Table 3) and further supports unidirectional bedload sediment transport via stream processes (Fig. 15C). Fining upward sequences are associated with the repeated flooding cycles and lateral channel migration typical of a braided-stream system (Fig. 15D). The high percentage of organic material present in sandstone channels indicates deposition in a humid, vegetated environment. The fragmented, disseminated nature of the organic material further supports deposition in a relatively high-energy environment of a braided stream system.

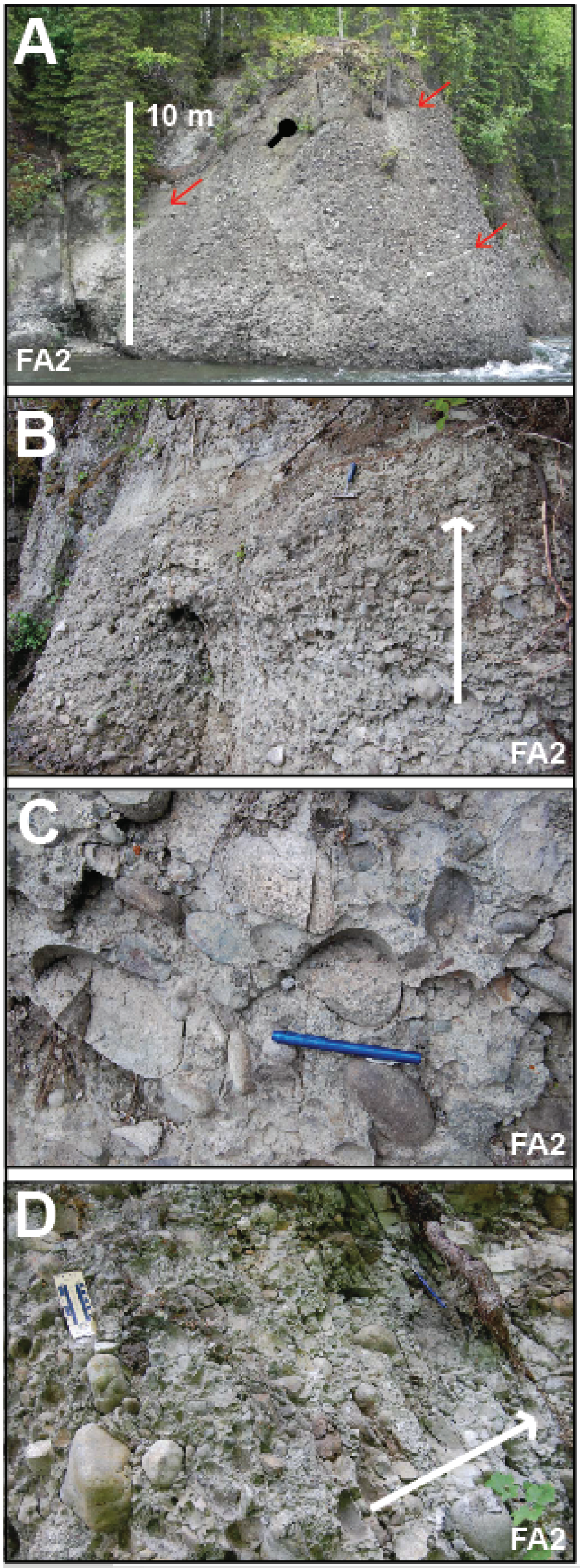


Figure 15. Representative photographs of the poorly to moderately sorted, pebble-cobble conglomerate of FA2 at Willow Creek. (A) Shows general bed geometry of exposed strata of FA2 along Willow Creek. Note thin interbeds of sandstone (red arrows) and finer-grained clast sizes compared to FA2. Black tadpole symbol denotes direction of dip (to the left in this photo) of bedding. (B) Fining upward sequence (white arrow) within pebble-cobble conglomerate. Lenticular sandstone channel at top of the sequence. Note hammer for scale near top of white arrow (C) Clast imbrication within FA2. See Table 3 for paleocurrent measurements from this location. Clasts dip to the right in photo. (D) Photograph of a fining upward sequence within a conglomerate bed in FA2. Overall, these photographs (A-D) document the better organization and higher percentage of sandstone within FA2 compared to FA1.

Table 1. Maximum Particle Size Measurements of Conglomerate Clasts in Lithofacies Association 1.

Stratigraphic Position	Pebble	Cobble		Boulder	
	3.2 - 6.4 cm	6.4 - 12.8 cm	12.8 - 25.6 cm	25.6 - 51.2 cm	51.2 - 102.4 cm
53.0 m	0	0	0	9	1
50.8 m	1	7	2	0	0
45.3 m	0	1	6	3	0
42.6 m	0	0	9	1	0
41.1 m	1	9	0	0	0
37.1 m	0	0	3	7	0
36.0 m	0	4	6	0	0
32.8 m	0	0	4	6	0
32.3 m	0	7	3	0	0
31.5 m	0	8	2	0	0
27.5 m	7	3	0	0	0
25.2 m	0	6	4	0	0
205 m	0	0	0	8	2
19.7 m	0	5	5	0	0
17.9 m	0	6	4	0	0
16.9 m	7	3	0	0	0
150 m	0	0	1	7	2
15.2 m	6	4	0	0	0
11.0 m	0	0	1	9	0
11.0 m	0	0	6	4	0
Total Clasts Count	**22**	**119**		**59**	

Stratigraphic position refers to position in the Willow Creek generalized section (Fig. 10). All measurements located between 11 and 53 m are located within measured section WC1 (Fig. 11). Table represents 200 total measurements; 22 pebble sized (11%), 119 cobble sized (59.5%), and 59 boulder sized (29.5%).

Table 2. Maximum Particle Size Measurements of Conglomerate Clasts in Lithofacies Association 2.

Stratigraphic Position (m)	**Pebble**	**Cobble**		**Boulder**	
	3.2 - 6.4 cm	6.4 - 12.8 cm	12.8 - 25.6 cm	25.6 - 51.2 cm	51.2 - 102.4 cm
328.6B m	0	6	3	1	0
327.7B m	0	2	7	1	0
326.8T m	8	2	0	0	0
326.8B m	0	6	3	1	0
325.7T m	8	2	0	0	0
325.7B m	0	7	2	1	0
324.0T m	9	1	0	0	0
324.0B m	0	4	6	0	0
321.9B m	0	4	6	0	0
321.1 m	0	8	2	0	0
320.0 m	0	7	3	0	0
Total Clasts Count	**25**	**81**		**4**	

Stratigraphic position refers to position in the Willow Creek generalized section (Fig. 10). All measurements are within measured section WC2 (Fig. 11). T = top of bed, B = base of bed. Table represents 110 total measurements; 25 pebble sized (23%), 81 cobble sized (74%), and 4 boulder sized (3%).

Lithofacies Association 3: Cross-stratified Sandstone

Description

Lithofacies association 3 (FA3) consists of coarse-grained, poorly sorted arkosic sandstone with mostly subangular to angular grains and represents 8% of the total thickness of exposed strata along Willow Creek. Channelized sandstone beds of this association make up amalgamated sequences with maximum preserved thickness up to 15 m thick and crop out exclusively in the middle section of exposed strata along Willow Creek. FA3 is characterized by horizontal stratification and ripple cross-stratification, abundant disseminated organic material, fining upward sequences, and minor pebble-cobble conglomerate interbeds. Figure 16 shows representative photographs of sedimentary structures and characteristics of FA3.

Interpretation

The sandstones of FA3 record streamflow deposition by sandy channels and longitudinal bars within a braided stream system on a humid, alluvial slope. Horizontal stratification and ripple cross-stratification record unidirectional waterlain bedload deposition under variable flow regime. Fining upward sequences represent lateral channel migration within the stream system. The minor, interbedded pebble-cobble conglomerate represents pebble-cobble channel lags deposited by waterlain bedload prior to lateral channel migration. Abundant organic material indicates sediment was deposited in a vegetated environment (Fig. 16C).

Lithofacies Association 4: Lava Flows

Description

Lithofacies association 4 (FA4) consists of black, aphanitic to amygdaloidal lava flows which crop out in the lower to middle 300 m of exposed strata along Willow Creek (Fig. 10). The lava flows have a maximum preserved thickness up to 65 m and represent 38% of exposed strata along Willow Creek. Bedding contacts with adjacent sedimentary rocks are scoured, erosive surfaces. Most individual flows grade upwards from a fine-grained lower massive unit with plagioclase phenocrysts to vesicular or amygdaloidal flow tops. Most exhibit diagenesis features, including replacement of vesicles by quartz and/or calcite. There is no evidence for syndepositional interaction with ponded water such as pillow structures, peperites, and hyaloclastites. Geochemical data are not reported from the lavas, but the dark gray to black appearance and lack of visible quartz indicates the flows are basalt to basaltic andesite in composition. Ongoing analyses will help verify geochemical composition. Figure 17 shows representative photographs of FA4 exposed along Willow Creek.

Interpretation

The basalts of FA4 are interpreted to be deposited by lava flows onto a high-gradient alluvial slope flanking active eruptive centers. The vesicular tops of beds are indicative of lava flows and form as a result of gases escaping through the upper portion of the flow. This distinguishing feature of lavas helps differentiate the exposed basalts along Willow Creek as lava flows versus exposed sills (Fig. 17B). Calcite and quartz amygdules later formed by secondary mineral precipitation infilling the vesicles after the lava flow cooled. The absence of pillow structures, peperites, and hyaloclastites suggests the lavas were not deposited within ponded water. The absence of vent-proximal lithofacies, such as volcanic breccia, agglomerate, or feeder dikes indicates that lava flows traveled distances of hundreds of meters or more from the eruptive center. This interpretation is consistent with deposition on an alluvial slope flanking the eruptive center.

MODERN DEPOSITIONAL ANALOG

The integration of new geologic mapping data from Kashwitna River Bluff and Willow Bench with the sedimentologic data from Willow creek helps aid in the construction of a model for sediment deposition of the Arkose Ridge Formation in the southwestern Talkeetna Mountains. The alluvial-fluvial strata exposed along Willow Creek are dominated by conglomerate and minor sandstone (Fig. 10) that are interpreted to be deposited by a proximal braided stream on a steep alluvial slope. Interbedded basalts are interpreted to be deposited by a proximal volcanic center because of the tens-of-meter thick packages of basalt interbedded within the Willow Creek section (Fig. 10). The Maelifell volcano and adjacent area in Iceland represents a modern depositional analog to the Willow Creek section and surrounding areas at Kashwitna River Bluff and Willow Bench (Fig. 18). The Maelifell volcano is pictured in Figure 18A with a gravelly braided stream system flanking the eruptive center. This spatial arrangement is similar to the inferred environments of deposition at the Willow Creek and the surrounding area (Fig. 4). Willow Creek would represent the proximal braided stream system that would

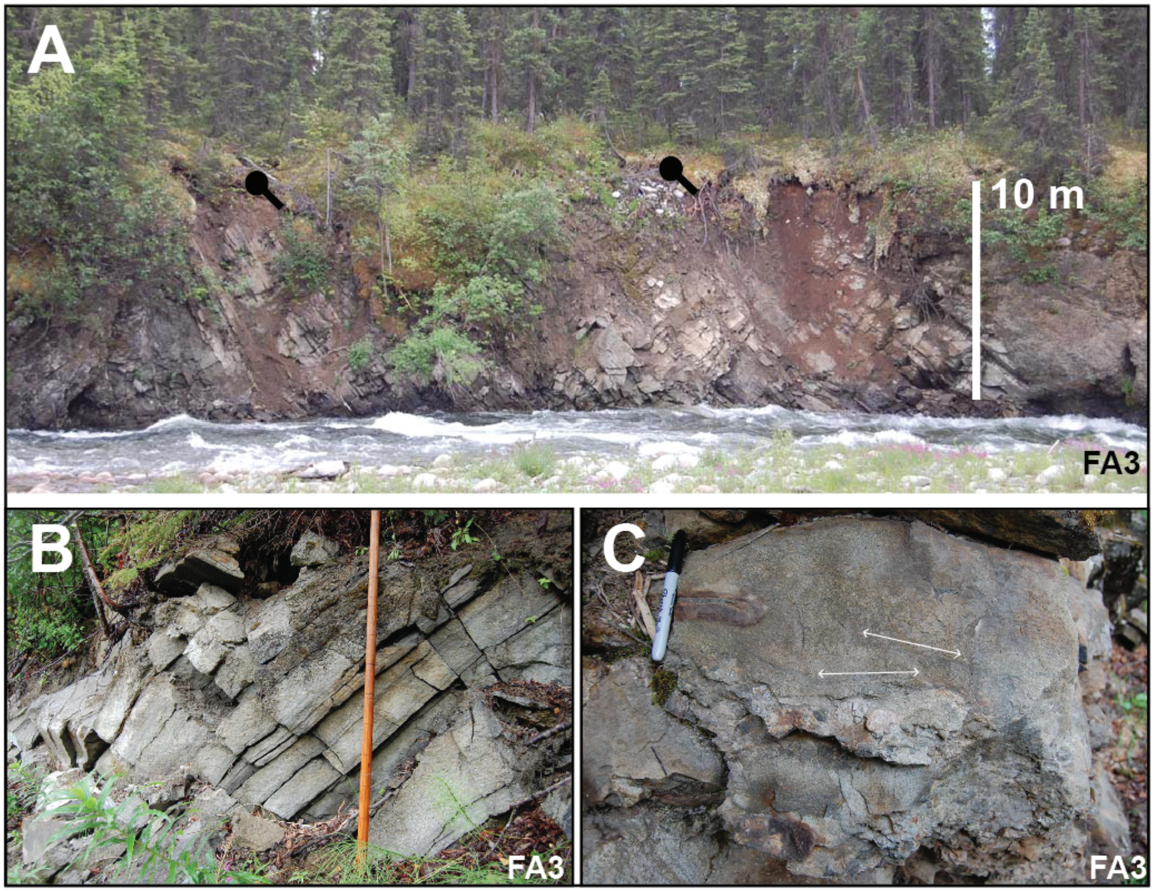


Figure 16. Representative photos of the coarse-grained, arkosic sandstone of FA3 at Willow Creek. (A) Amalgamated beds of FA3 exposed along Willow Creek. Black tadpole symboles indicate the dip of bedding (to the right in image). (B) Example of horizontally stratified sandstone in FA3 with scoured bases of lowermost beds. 1.5 meter jacob staff for scale. (C) Pebble-cobble conglomerate lags and horizontal stratification (white arrows) diagnostic of FA3 sandstone.

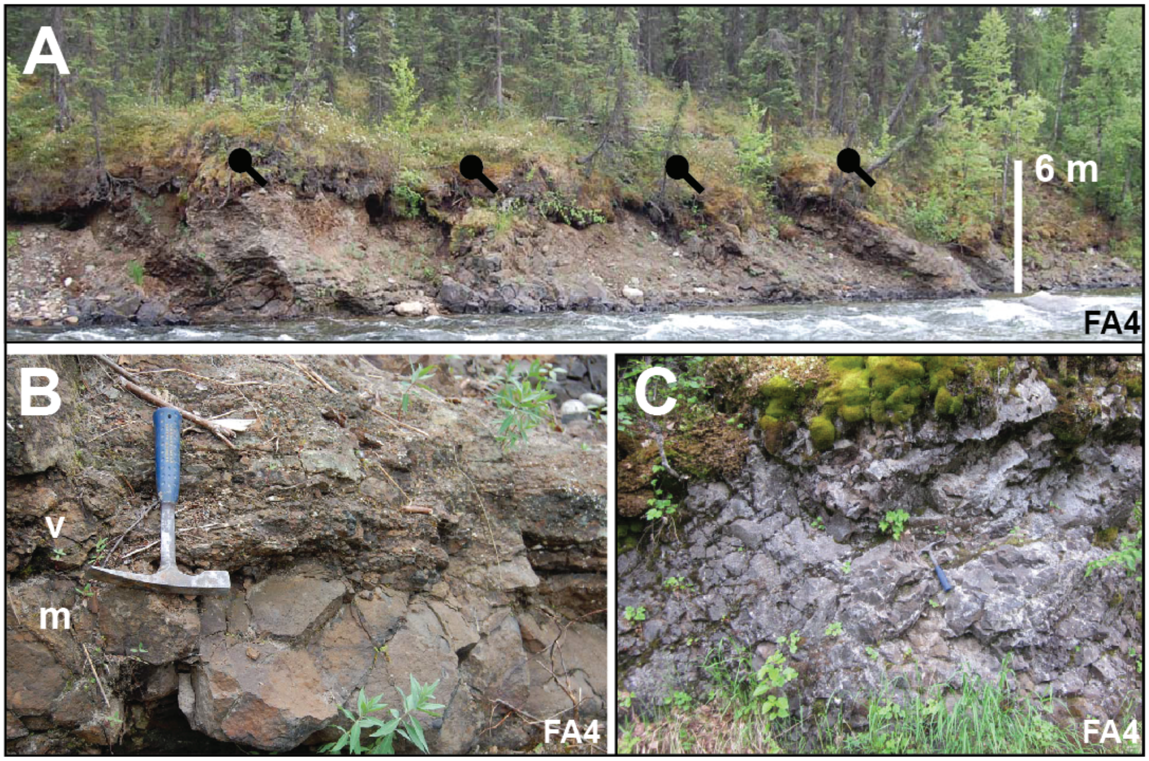


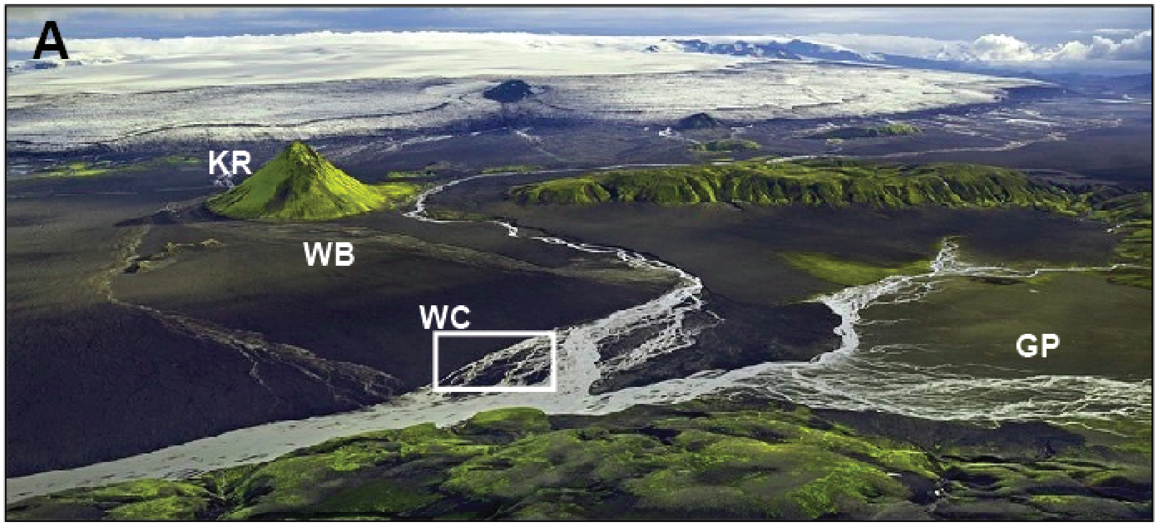
Figure 17. Representative photographs of the lava flows of FA4 at Willow Creek. (A) Shows general bed geometries of four distince lava flows. Black tadpole symbols indicate the direction of dip in bedding for each flow (to the right in photo). Lower, massive parts of flows are more resistant to weathering and form more prominent outcrops below tadpole symbols. (B) Photo shows vesicular (v) upper portion of a lava flow above a massive (m), aphanitic lower portion of the flow. Note light-colored infilled amygdules by calcite and quartz in vesicular portion of flow. (C) Shows massive, aphanitic mafic lava flow. Note hammer in center of photo for scale.

be flanking potential eruptive centers at Willow Bench and the Kashwitna River Bluff. The basalts that were deposited at Willow Creek are interpreted to have been deposited in the same manner shown in Figure 18A, where episodic volcanic eruptions would cause thick lava flows to be deposited within the braided stream system. A photograph taken at the braided stream that flanks the Maelifell volcano (Fig. 18B) reveals rounded clasts with similar sizes that are comparable to the conglomerate lithofacies (FA1 and FA2) of Willow Creek (Fig. 13). This indicates that the depositional processes and environments of the braided stream system proximal to the Maelifell volcano are comparable to those that deposited the Willow Creek strata.

PROVENANCE DATA

Sedimentological, compositional, and geochronological data are well-documented for the eastern outcrops of Arkose Ridge Formation in the southern Talkeetna Mountains, helping constrain provenance and reconstruct environments of deposition (Cole *et al*., 2006; Kortyna, 2011; Idleman *et al*., 2011). No previous sedimentological or compositional data have been reported prior to this study from the strata exposed along Willow Creek, the westernmost outcrop of Arkose Ridge Formation. New conglomerate clast counts (n = 707), paleocurrent measurements (n = 10), and U-Pb ages of detrital zircons (n = 4), granitoid clasts in conglomerate (n = 3), and granitoid intrusions (n = 4) from Willow Creek and the Government Peak area help document source terranes and sediment provenance of southwestern outcrops of the Arkose Ridge Formation. These new data aid in constraining the locations and timing of erosion of potential bedrock

Figure 18. Modern depositional analog for strata exposed along Willow Creek. (A) Aerial photo of the Maelifell volcano and adjacent area in Iceland (Strand, 2006). Representative of a proximal, braided stream system influenced by periodic volcanic eruptions. Abbreviations are as follows: KR-Kashwitna River Bluff; WB-Willow Benchmark; WC-Willow Creek. (B) Image of a braided stream system influenced by volcanic eruptions showing representative clast sizes of the conglomerate exposed at Willow Creek. Note proximal location to bedded, mafic rocks which supports clast count data (Table 1 and Table 2).


A
KR
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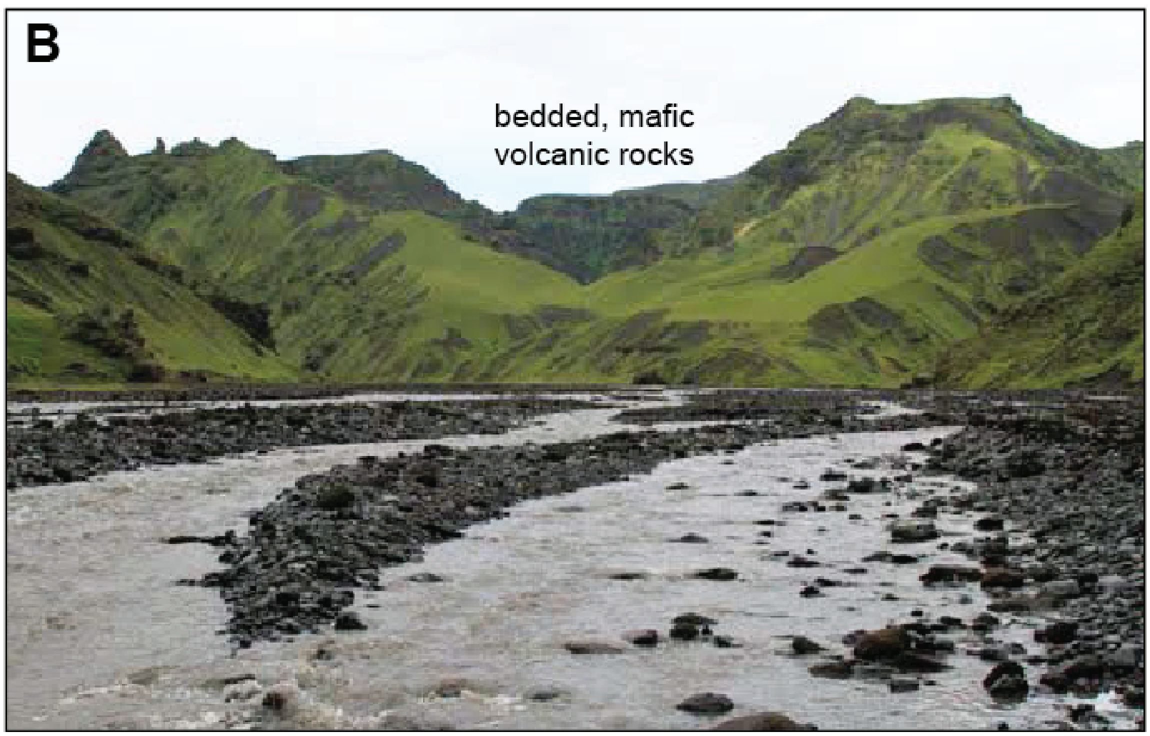

B
bedded, mafic
volcanic rocks

sources, reconstructs sediment transport pathways, and in refining a previously established depositional model for the Arkose Ridge Formation (Kortyna, 2011).

Paleocurrent Measurements

Paleocurrent data were collected from one location in FA2, within the measured section WC2, along Willow Creek. Data represents the orientation of 10 imbricated clasts from one conglomerate bed and documents a southeastward-directed paleocurrent trend (Table 3). All measurements were structurally restored to horizontal by correcting for the 50°–60º dip of beds. See Figure 5 for location of paleocurrent measurements and rose diagram of paleocurrent data. These data indicate source terranes located north of the Willow Creek area (Fig. 3) were important sources of detritus during deposition of the exposed strata.

Paleocurrent measurements from the Willow Creek area are similar with previously collected measurements in Paleocene–Eocene alluvial-fluvial strata in the Talkeetna Mountains, including the Arkose Ridge Formation (Fig. 19). The paleocurrent indicators document southeast-, south, and southwest-directed sediment transport along the northern margin of the Arkose Ridge Formation outcrop belt, indicating erosion of the source terranes presently exposed in the Talkeetna Mountains or farther north.

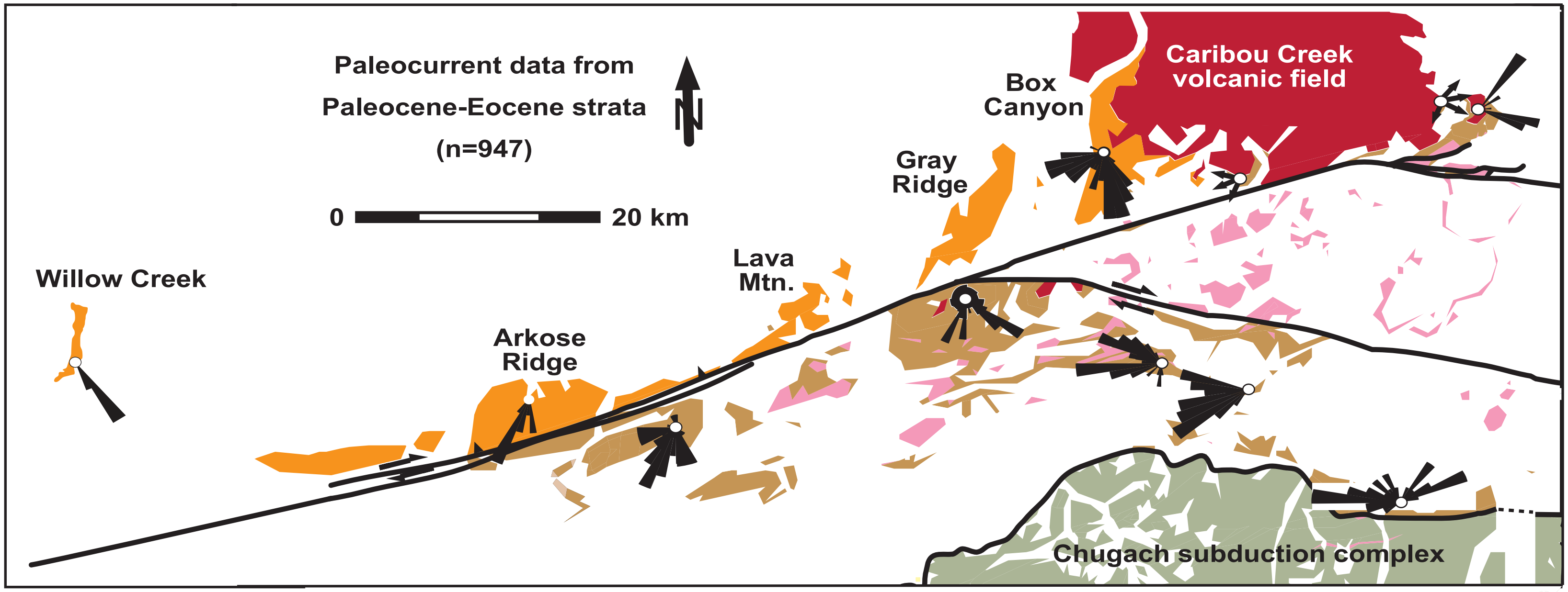


Figure 19. Map showing sediment transport directions measured in Paleocene-Eocene strata, including Arkose Ridge Formation (ARF) strata exposed north of the Castle Mountain fault. n = total number of paleocurrent measurements. All measurements were corrected for structural tilt if necessary. Note southeastward- to southwestward-directed paleoflow along the northern basin margin, westward-directed paleoflow along the axis of the basin, and northeastward- to northwest-directed paleoflow along the southern basin margin. Note new paleocurrent measurements (n = 10) from this study are measured at Willow Creek that indicate a southeastward paleoflow. Adapted from Trop (2008).

Table 3. Strike/dip and azimuths of paleocurrent measurments of imbricated clasts in the FA2 conglomerate

Measurements	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
Stike/Dip Dip Direction	045, 45 NW	042, 47 NW	062, 59 NW	043, 55 NW	060, 66 NW	039, 57 NW	056, 38 NW	042, 47 NW	045, 66 NW	049, 52 NW	
Paleoflow Azimuth	135	132	152	133	150	129	146	132	135	139	**138**
Paleoflow Azimuth Corrected for dip	146	144	155	145	154	142	152	144	146	148	**148**

Note: Measurements were restored based on strike and dip measurement of 158, 60 SW from adjacent sandstone bed. See Figure 5 for location.

Conglomerate Clast Composition

Conglomerate clast counts were obtained from seven different pebble-cobble conglomerate beds of FA1 and FA2 (n = 707; individual clasts). Conglomerate clast counts document primarily volcanic (60% of all documented clasts) and plutonic lithologies (38% of all documented clasts) in the FA1 and FA2 conglomerate. See Table 4 for raw and summary data of conglomerate clast counts.

The volcanic category is characterized by two types of mafic clasts which are green to black in color and resemble basalt and basaltic andesite compositions based on field identifications. The green basalt variety is coarser-grained with coarse-grained plagioclase laths. Black basalts are typically aphanitic and often have a higher percentage of siliceous material and glass compared to the basaltic andesite. The plutonic category is characterized predominantly by coarse-grained, non-foliated felsic plutonic clasts including granodiorite, diorite, and quartz diorite. Of the 272 plutonic clasts documented, 82% (223 clasts) are felsic in composition and 18% (49 clasts) are mafic in composition. Mafic plutonic clasts are characterized by an aphanitic, green intrusive rock, possibly gabbro. The other clast type category, composing 2% of all documented clasts, is characterized by different varieties of tuff and chert. Figure 20 shows representative photographs of volcanic and plutonic clast types as well as histograms of compositional data from all localities in stratigraphic order.

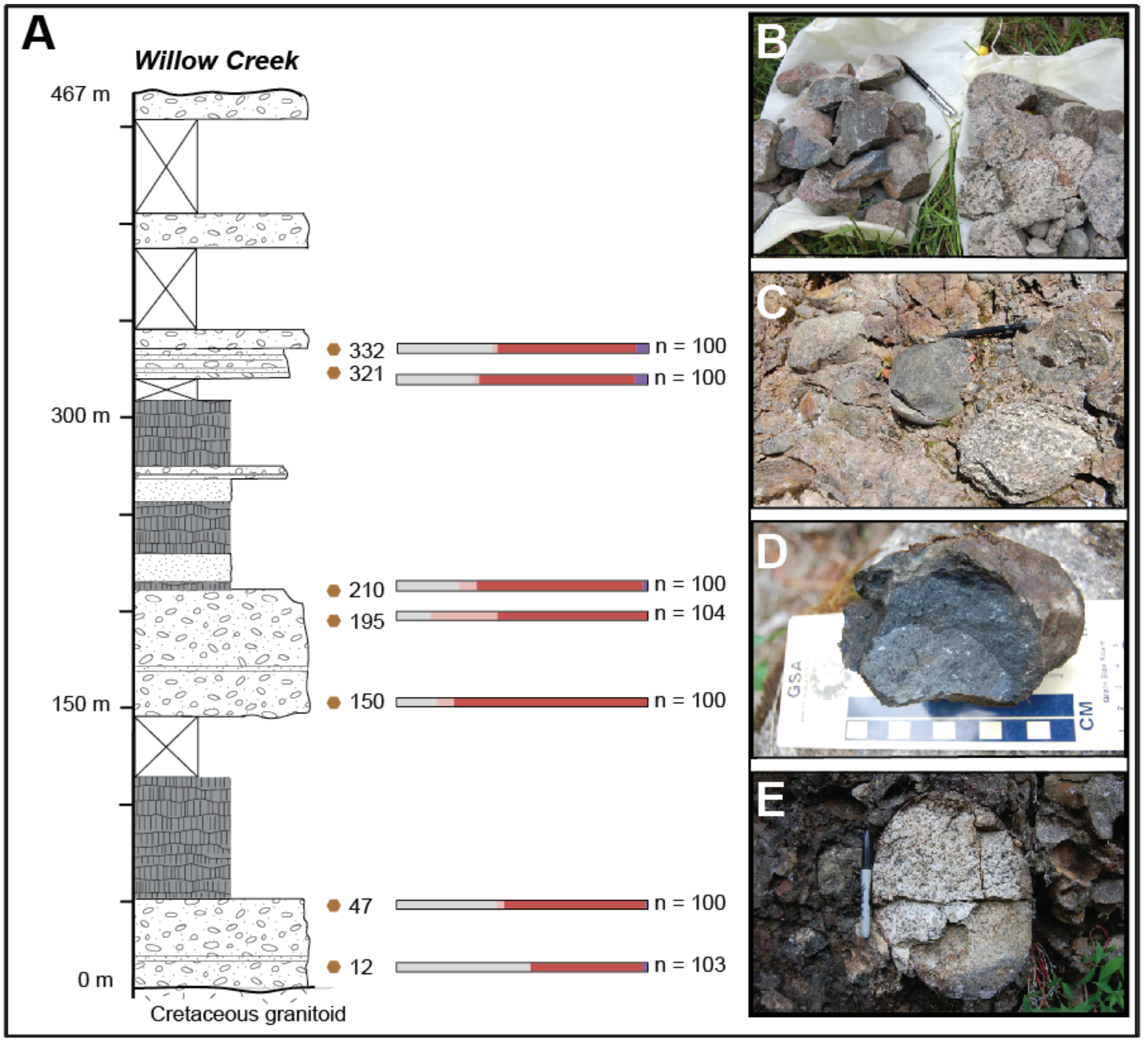


Figure 20. (A) Generalized section showing clast compositional data (histograms) from conglomerate exposed along Willow Creek. Brown hexagons represent stratigraphic position (number labels to right, in meters). Percentages of plutonic clasts (grey and light pink color), volcanic clasts (red), and other clast (purple) lithologies are shown in histograms (n = number of individual clasts counted). Note dominance of volcanic clasts at all stratigraphic positions and no apparent upsection change in clast types. Photographs B-E document representative clast lithologies. (B) Basalt (left) and granitic (right) clasts collected from conglomerate. (C) Basalt (left) and granite (right) clasts in situ. (D) Basalt clast. (E) Granite clast. See text for description of clast types and Figure 5 for clast count locations on geologic map.

Table 4. Clast count data for conglomerate of the Arkose Ridge Formation at Willow Creek

Clast Type (lithology, color, grain size)	CC1 **12 m**	CC2 **47 m**	CC3 **150 m**	CC4 **195 m**	CC5 **210 m**	CC6 **321 m**	CC7 **332 m**	**Summary**
Raw								
Felsic Plutonic								
granodiorite/diorite, weathers red, coarse	55	40	16	14	25	31	38	219
quartz diorite, white	2	1	0	0	0	0	1	4
Mafic Plutonic								
mafic intrusive, green, fine	0	3	7	28	7	2	2	49
Mafic-Intermediate Volcanic								
basalt/basaltic andesite, green to black, fine	46	56	77	62	66	65	55	427
Other								
tuff/tuff-breccia, tan/grey	0	0	0	0	0	5	4	9
chert, green to grey	0	0	0	0	2	0	0	2
Total number of clasts counted	**103**	**100**	**100**	**104**	**100**	**100**	**100**	**707**
Recalculated								
% Felsic Plutonic	55.34	41.00	16.00	13.46	25.00	31.00	39.00	**31.54**
% Mafic Plutonic	0.00	3.00	7.00	26.92	7.00	2.00	2.00	**6.85**
% Mafic-Intermediate Volcanic	44.66	56.00	77.00	59.62	66.00	65.00	55.00	**60.46**
% Other	0.00	0.00	0.00	0.00	2.00	5.00	4.00	**1.57**

Notes: m = stratigraphic position (in meters) of clast count sample location within the generalized section of Willow Creek (Fig. 10). See Figure 5 for sample location on geologic map of Willow Creek.

Sandstone Petrography

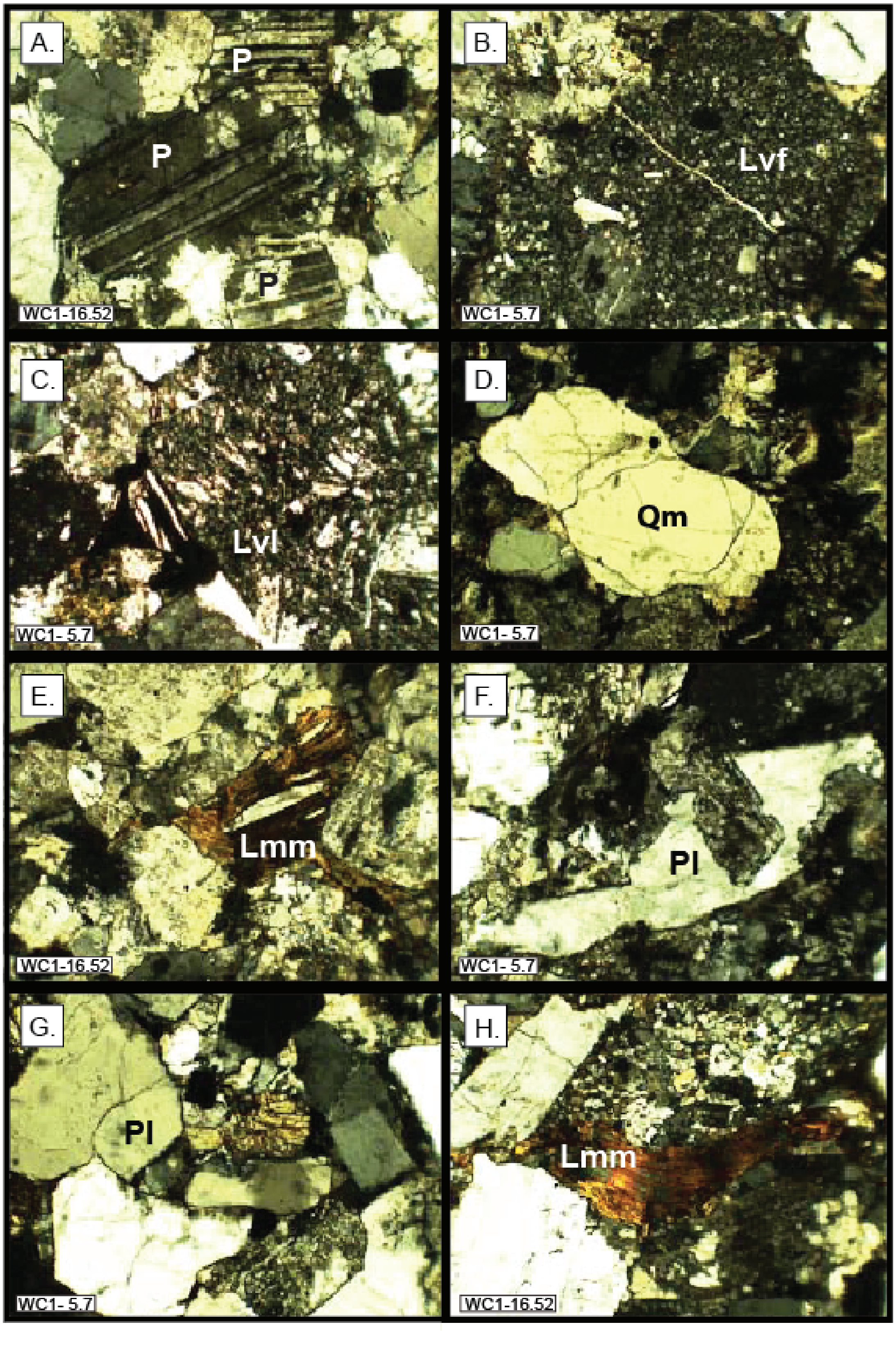
Thin section photomicrographs taken from four sandstone samples within measured sections WC1 and WC2 (Fig. 11) document the common framework grains present within poorly sorted medium- to very-coarse-grained sandstone of lithofacies association three (FA3) exposed at Willow Creek. Photomicrographs show sampled sandstones from Willow Creek have representative grains from the average framework grain modes consisting of quartz, feldspar, and lithics defined by the Gazzi-Dickinson method (Dickinson, 1970; Ingersoll *et al.,* 1984). The quartz population is dominated by monocrystalline quartz and quartz subgrains within plutonic lithic fragments (Fig. 21). Subangular plagioclase grains and plagioclase subgrains within plutonic lithic fragments make up the feldspar population. Subordinate low-grade metamorphic lithic grains and volcanic lithic grains make up the remainder of the lithic population. Metamorphic grains consist of mica schist whereas volcanic grains are dominated by lathwork grains with visible plagioclase phenocrysts and minor felsic volcanic grains with visible quartz and feldspar microlites. Overall, thin sections are dominated by a high abundance of plutonic fragments.

U-Pb Geochronology

Igneous U-Pb Zircon Ages

Granitoid intrusion samples were collected for geochronologic analyses, including two samples (G.R. Granite and 072510KRI) exposed along Willow Creek and one sample (ED2) exposed at Willow Bench. Sample 072510KRI was collected directly

Figure 21. Photomicrographs of representative framework grains from Willow Creek sandstone samples from measured section WC1. See Figure 11 for sample locations. (A) Three monocrystalline plagioclase (P) feldspar grains. (B) Felsic volcanic lithic grain (Lvf) with feldspar and quartz microlites. (C) Lathwork volcanic lithic grain (Lvl) with plagioclase feldspar laths. (D) Single monocrystalline quartz grain (Qm). (E) and (H) Biotite schist fragments (Lmm). (F) and (G) Plutonic lithic grains (Pl) with quartz and plagioclase feldspar subgrains. All photomicrographs are taken in cross-polarized light. Thin sections are stained for plagioclase (red stain) feldspar.


A.
P
P
P
WC1-16.52
B.
Lvf
WC1- 5.7
C.
Lvl
WC1- 5.7
D.
Qm
WC1- 5.7
E.
Lmm
WC1-16.52
F.
Pl
WC1- 5.7
G.
Pl
WC1- 5.7
H.
Lmm
WC1-16.52

below the unconformity in context of the generalized stratigraphic section (Fig. 10) and geologic map of Willow Creek. See Figure 5 for sample location along Willow Creek, Figure 10 for stratigraphic position, and Figure 22 for age histograms of individual spot analyses for all granitoid pluton samples. The G.R. Granite sample was collected approximately 2 km upstream of the sample location for 072510KRI. Refer to Figure 6 for a geologic map of the Willow Bench area with location of sample ED2. The G.R. Granite sample yields a mean age of 72.0 ± 1.4 Ma (n = 28; n = total number of zircon grains), sample 072510KRI yields a mean age of 73.5 ± 1.4 Ma (n = 30), and sample ED2 yields a mean age of 71.2 ± 2.1 Ma (n = 16).

Three granitoid clasts were collected from Willow Creek conglomerate lithofacies association one (FA1) for U-Pb geochronologic analyses. Two samples (WC1-3.5 and WC1-11.5) were collected within context of measured stratigraphic section WC1 directly above the granitoid contact and one sample (062110JTI) was collected at 400 m from the generalized measured stratigraphic section of Willow Creek. See Figure 5 for sample locations along Willow Creek and Figure 10 for stratigraphic position. Sample WC1-3.5 yields a mean age of 73.6 ± 1.2 Ma (n = 23) and sample WC1-11.5 yields a mean age of 85.8 ± 2.0 Ma (n = 30). Sample 062110JTI differs considerably in age from the other clasts, yielding a range of ages ranging from 214 to 190 Ma (n = 30). See Figure 23 for age histograms of individual spot analyses for all three granitoid clasts.

One sample (ED17) of previously undated granitoid along Bald Mountain Ridge, ~10 km west of Government Peak, was collected for geochronologic analyses (Fig. 4). Sample ED17 yields a mean age of 81.0 ± 1.4 Ma (n = 24). See Figure 24 for an age

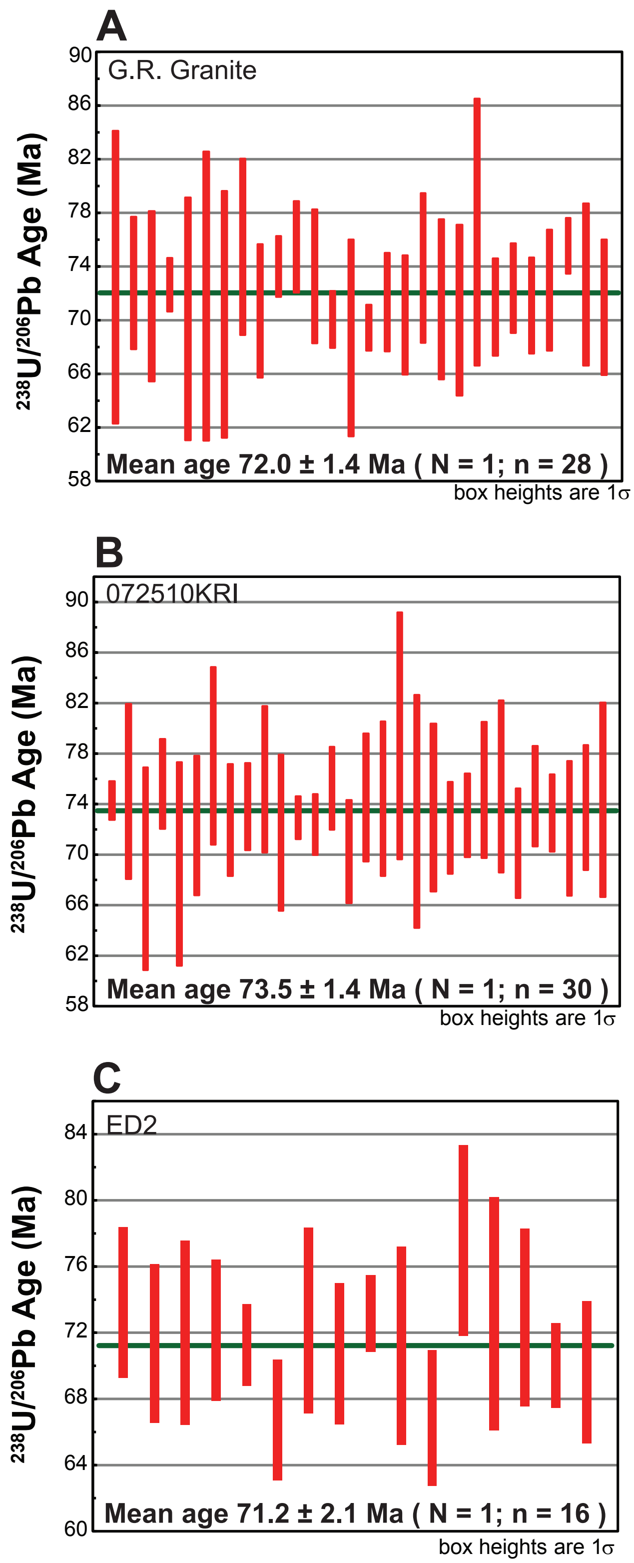


Figure 22. Age histograms of zircons from granitoid pluton that underlies sedimentary-volcanic strata exposed at Willow Creek (A-B) and the Willow Bench area (C). See Figure 4 for sample locations. Green bar on histogram represents mean age of spot analyses on individual zircon grains. Ages with 1σ error are plotted. N = number of samples, n = total number of zircon grains.

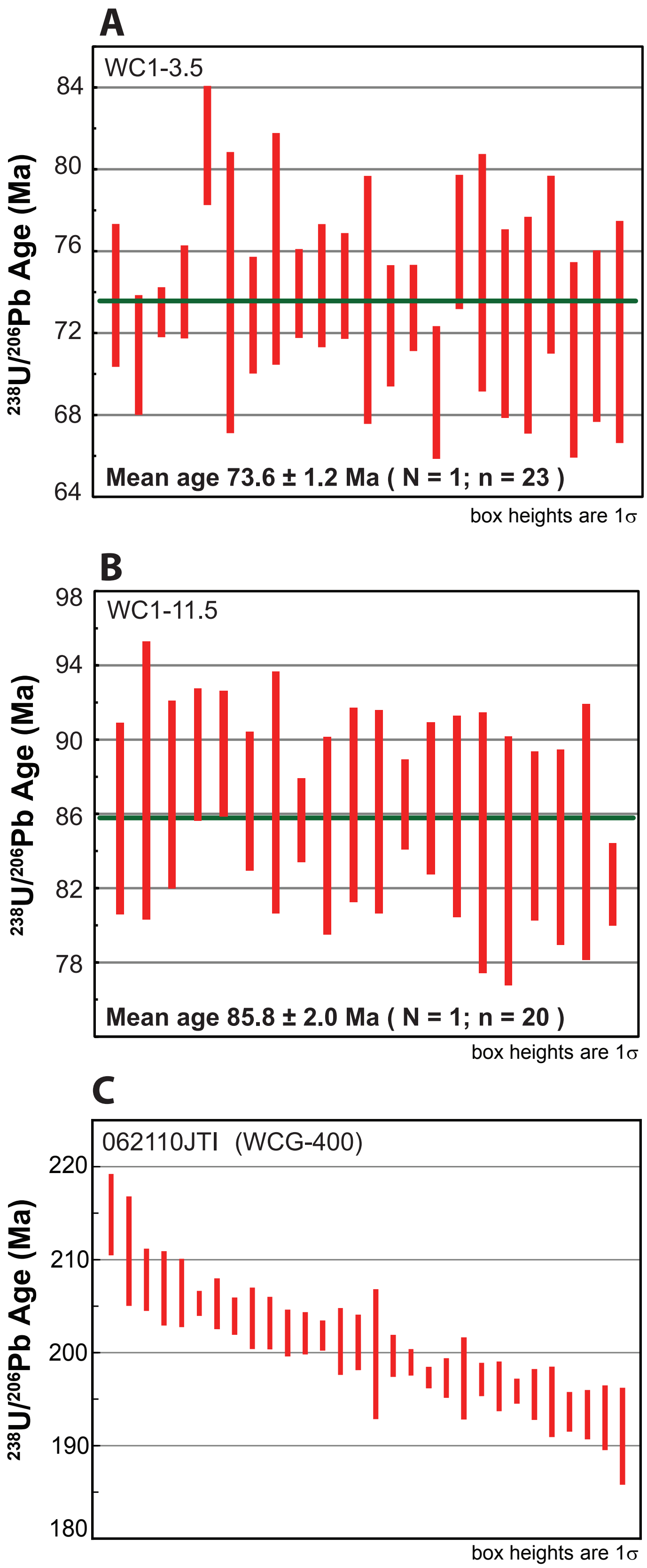


Figure 23. Age histograms of zircons from three granitoid clasts (A-C) taken from Willow Creek conglomerate facies association one (FA1). See Figure 5 for sample locations. Green bar on histogram represents mean age of spot analyses on individual zircon grains. Ages with 1σ error are plotted. The wide range of ages (190-214 Ma; n = 30) for sample 062110JTI (C) indicates the granitoid has a complex cooling history. N = number of samples, n = total number of zircon grains. Abbreviations: WC1-Willow Creek measured section 1, WCG-Willow Creek generalized measured section; number following dash indicates stratigraphic position from base in meters.

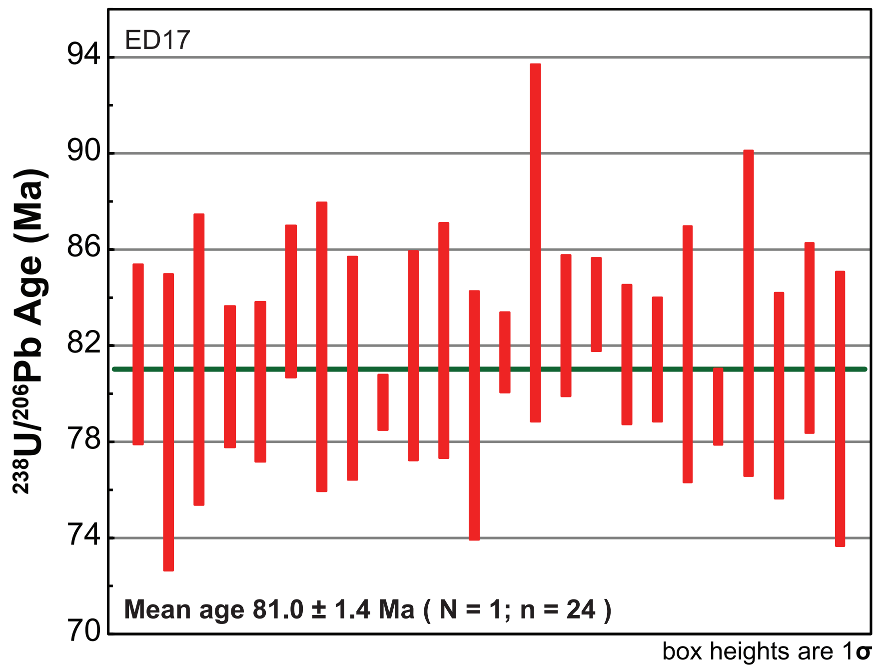


Figure 24. Age histograms of zircons from granitoid pluton that underlies sedimentary-volcanic strata exposed along Bald Mountain Ridge in the Government Peak area. See Figure 4 for sample location. Green bar on histogram represents mean age of spot analyses on individual zircon grains. Ages with 1σ error are plotted. N = number of samples, n = total number of zircon grains.

histogram of individual spot analyses for sample ED17.

Detrital U-Pb Zircon Ages

Two coarse- to medium-grained sandstone samples were collected for detrital geochronologic analyses in context of the generalized stratigraphic section and geologic map of Willow Creek. Figure 10 shows stratigraphic position of both samples and Figure 5 shows sample location on the geologic map of Willow Creek. Samples 071710CMK12 and 062110JT2 were collected at two separate locations in minor sandstone interbeds in primarily conglomeratic outcrops of FA1. A total of 189 individual zircon grain analyses document mainly Late Cretaceous to Paleocene ages (95% of all analyzed grains) and subordinate Early Cretaceous to Jurassic populations (5%). Probability curves show three main age populations that dominate analyzed zircon grains: 85–60 Ma (Latest Cretaceous to Early Paleocene; 63%), 100–85 Ma (Early Late Cretaceous; 30%), and 200–100 Ma (Early Cretaceous to Jurassic; 5%) (Fig. 25). See Table 5 for a summary of detrital geochronology analyses. Greater than 99% of all analyzed grains document U-Th ratios < 10 (Fig. 26).

Two granular to coarse-grained sandstone samples were collected for detrital geochronologic analyses from the Government Peak area (Fig. 4) and a total of 160 individual zircon grain analyses document exclusively Late Cretaceous ages (100% of all analyzed grains). Probability curves indicate that one main age population dominates analyzed zircon grains: 84–77 Ma (Latest Cretaceous; 63%) with subordinate 77–68 Ma (Latest Cretaceous; 19%) and 98–85 Ma (early Late Cretaceous; 18%) age populations

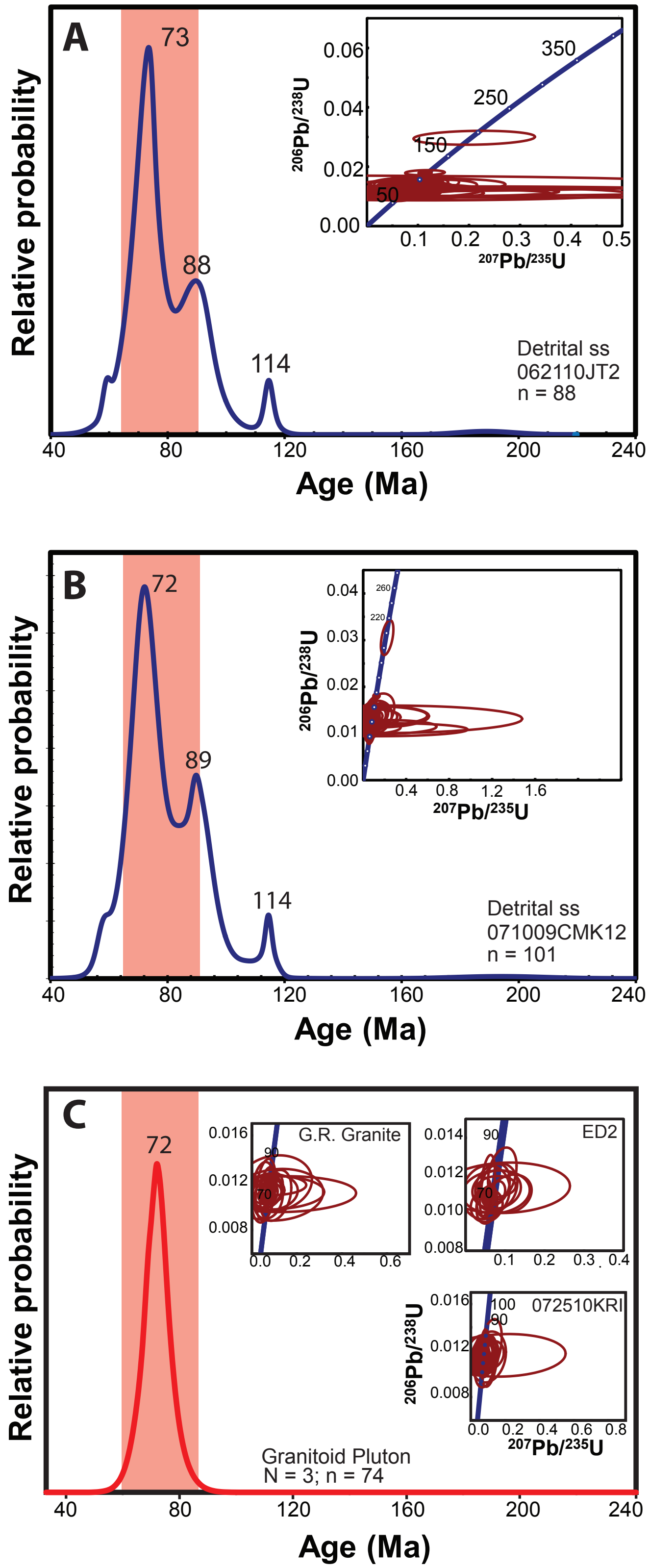


Figure 25. Age probability plots showing distribution of U-Pb age determinations of 189 detrital zircon grains from two Willow Creek sandstone samples (A-B; blue) and 74 U-Pb zircon grains from three samples of granitoid pluton (C; red) underlying the Willow Creek section (G.R. Granite and 072510KRI) and Willow Bench (ED2). Ages represent individual spot analyses from separate detrital zircon grains. U-Pb ages are plotted as a normalized relative-probability distribution (Ludwig, 2003). Relative heights of peaks correspond to statistical significance. Pink bar represents 65-90 Ma age range of underlying and adjacent Cretaceous plutons (TKg on Fig. 3). Note main age population of sandstone samples matches age of underlying pluton. Insets show concordia plots of individual spot analyses with sigma error ellipses. N = number of samples, n = total number of zircon grains.

Table 5. Summary of detrital ages for sandstone samples at Willow Creek

Period	Late Paleocene-Eocene	Latest Cretaceous-Early Paleocene	Early Late Cretaceous	Early Cretaceous-Jurassic	Triassic	Devonian-Mississippian	Cambrian	Precambrian	
Age (Ma)	60-48 Ma	85-60	100-85	200-100	251-200	416-318	488-542	>542 Ma	Total
Sample 071710CMK12									
# grains	3	62	31	5	0	0	0	0	101
%	3.0%	61.4%	30.7%	4.9%	0.0%	0.0%	0.0%	0.0%	100.0%
Sample 062110JT2									
# grains	1	57	26	4	0	0	0	0	88
%	1.1%	64.8%	29.5%	4.5%	0.0%	0.0%	0.0%	0.0%	100.0%
Summary of detrital ages from Willow Creek (N=2)									
# grains	4	119	57	9	0	0	0	0	189
%	2.1%	63.0%	30.1%	4.8%	0.0%	0.0%	0.0%	0.0%	100.0%

Notes: N = number of samples analyzed. See Figure 5 for sample locations.

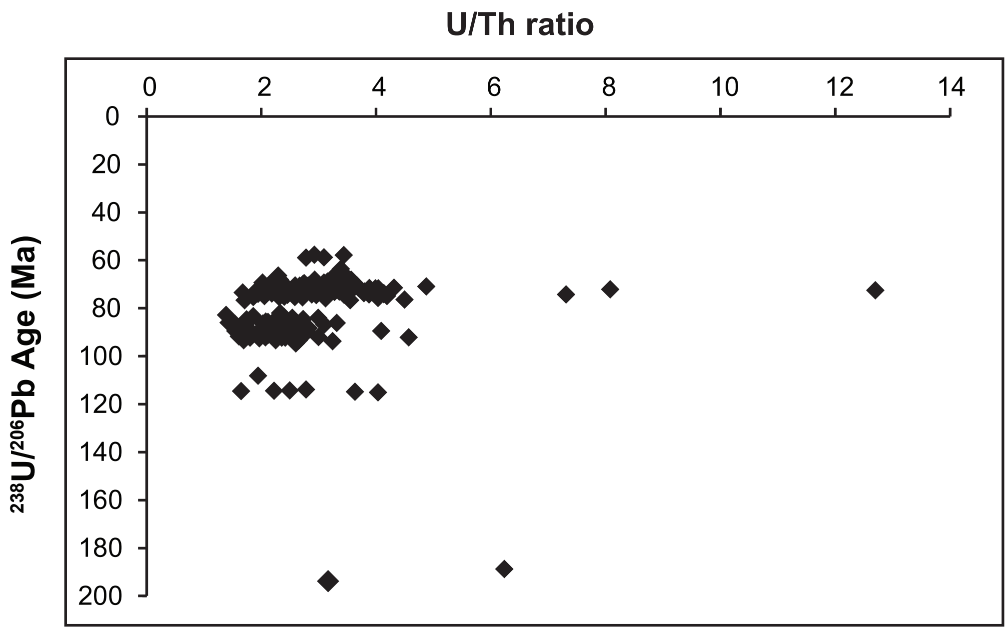


Figure 26. U/Th vs. U/Pb age of spot analyses of 189 detrital zircon grains from two sandstone samples at Willow Creek. Note >99% of detrital zircons yield <10 U/Th ratio indicating nearly all zircons are almost exclusively igneous in origin (Gehrels, 2012).

(Fig. 27). Sample GP3 was collected at Government Peak at 55 m above the base of a measured stratigraphic section that consists primarily of coarse-grained, poorly sorted arkosic sandstone and minor conglomerate and sparse carbonaceous mudstone (Fig. 28). Sample ED14 was collected ~10 km west of Government Peak along Bald Mountain Ridge, in a section dominated by granular to coarse-grained, arkosic sandstone (Fig. 9). See Table 6 for a summary of detrital ages from the Government Peak area. All analyzed grains document U-Th ratios < 10 (Fig. 29).

MAXIMUM DEPOSITIONAL AGE

The maximum depositional age can be determined by the youngest detrital zircon ages (3 or more to be statistically significant; Dickinson and Gehrels, 2009) to constrain and upper limit for when strata were deposited. Late Paleocene to Eocene age detrital zircon populations (2% of all analyzed grains) from Willow Creek sandstone samples are 60–48 Ma and include 59–57 Ma ages (100%), representing the youngest age population of all analyzed detrital zircon grains, providing insight on the age of sampled strata. The youngest zircon ages of all analyzed grains constrains the maximum depositional age of the Willow Creek strata. See Figure 30 for an age histogram of the four youngest grains from both detrital sandstone samples. Low-precision K-Ar analyses on a whole rock sample of an interbedded lava flow from the Willow Creek section yields a depositional age of 56.2 ± 1.7 Ma (Silberman and Grantz, 1984). Overlap of the K-Ar age with the youngest detrital zircon population supports deposition during the Late Paleocene to Eocene (Idleman *et al.*, 2011).

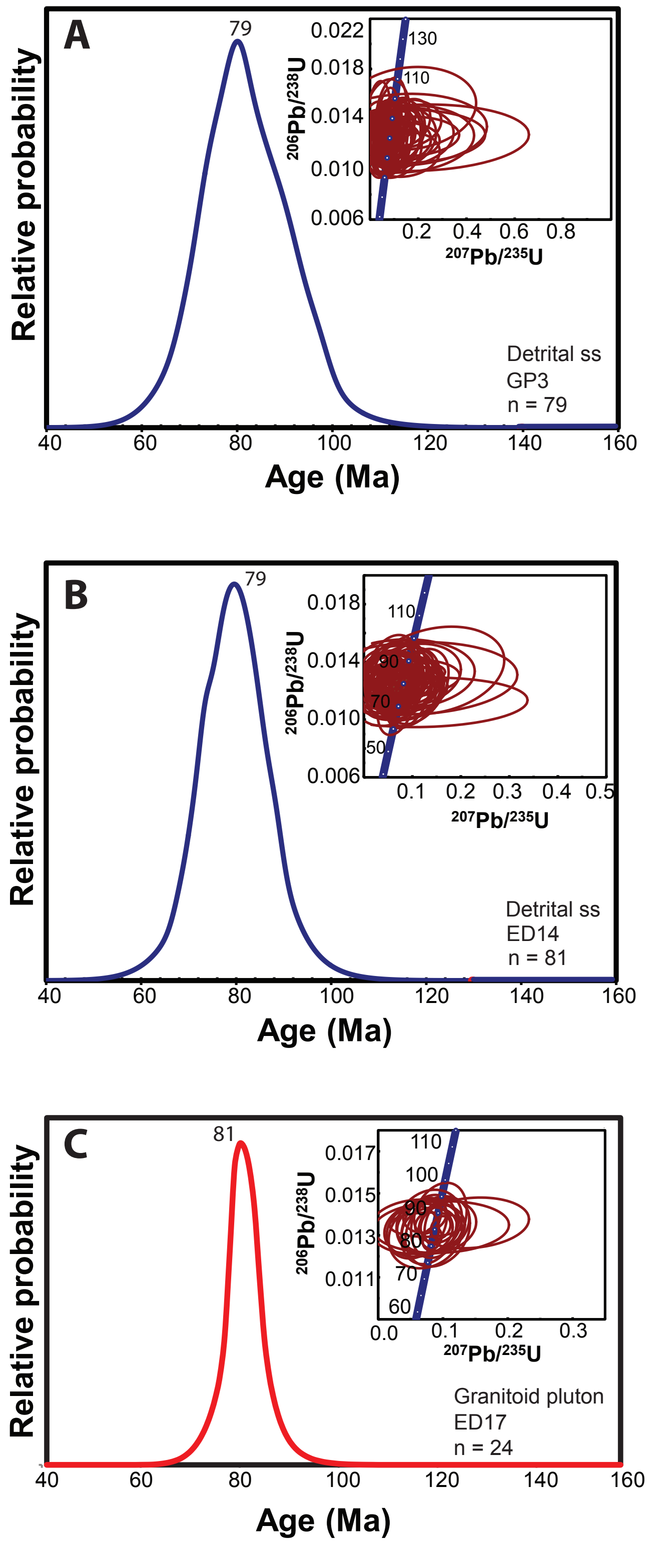


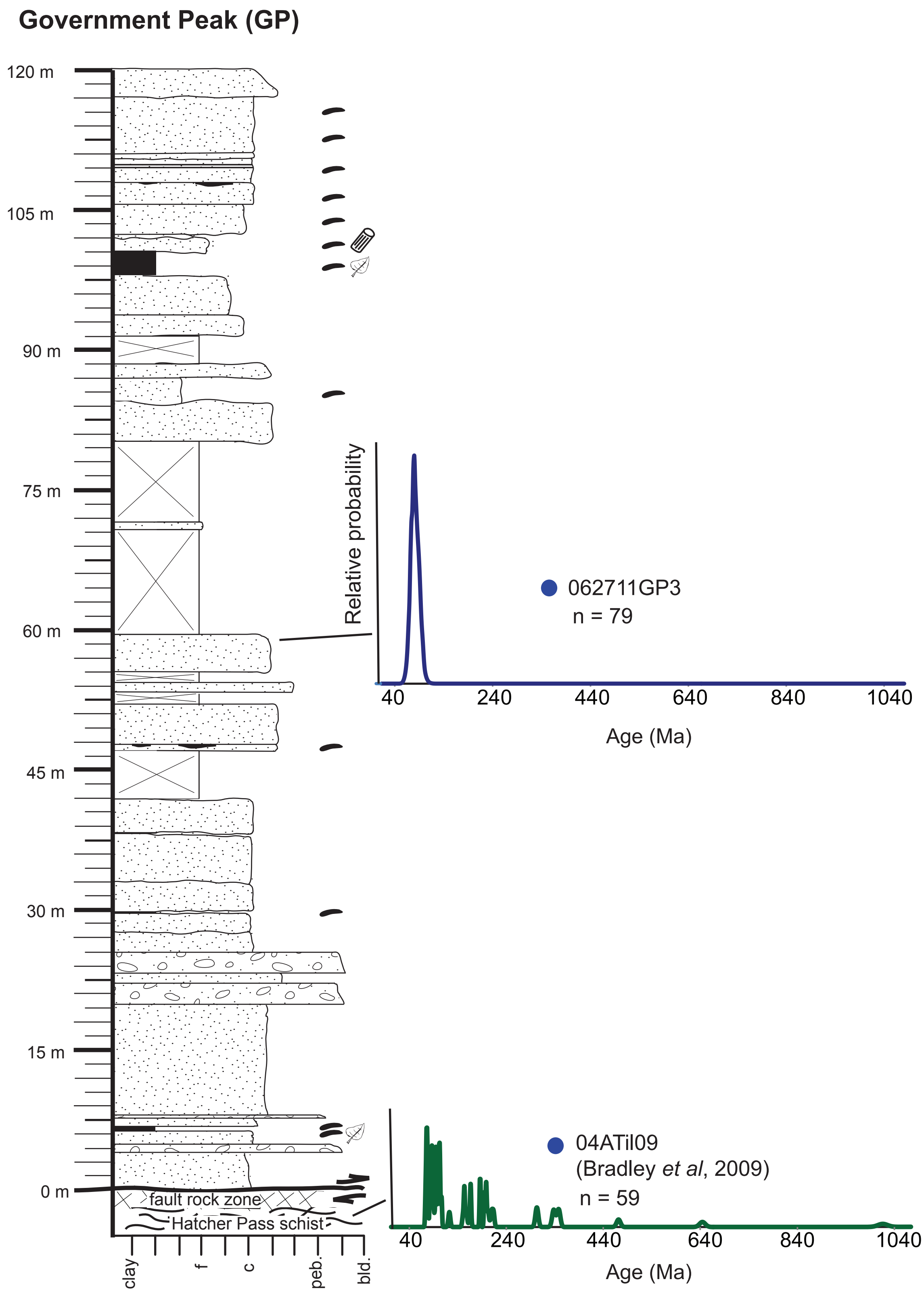
Figure 27. Age probability plots showing distribution of U-Pb age determinations of 160 detrital zircon grains from two Government Peak sandstone samples (A and B; blue) and 24 U-Pb zircon grains from one sample of granitoid pluton (C; red) underlying Government Peak samples. Ages respresent individual spot analyses from separate detrital zircon grains. U-Pb ages are plotted as normalized relative-probability distribution (Ludwig, 2003). Relative heights of peaks correspond to statistical significance. Note that the peak population of sandstone samples matches age of underlying pluton. Insets show concordia plots of individual spot analyses with sigma error ellipses. N = number of samples, n = total number of zircon grains.

Table 6. Summary of detrital ages for sandstone samples from Government Peak area

Period	Late Paleocene-Eocene	Latest Cretaceous-Early Paleocene	Early Late Cretaceous	Early Cretaceous-Jurassic	Triassic	Devonian-Mississippian	Cambrian	Precambrian	
Age (Ma)	60-48 Ma	85-60	100-85	200-100	251-200	416-318	488-542	>542 Ma	Total
Sample GP3 (Government Peak)									
# grains	0	57	22	0	0	0	0	0	79
%	0.0%	72.2%	27.8%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Sample ED14 (Bald Mountain Ridge)									
# grains	0	75	6	0	0	0	0	0	81
%	0.0%	92.6%	7.4%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Summary of detrital ages from Government Peak area (N=2)									
# grains	0	132	28	0	0	0	0	0	160
%	0.0%	82.5%	17.5%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%

Notes: N = number of samples analyzed. See Figure 8 for sample locations.

Figure 28. Bed-by-bed measured stratigraphic section of strata exposed along Government Peak. The measured section starts in the Arkose Ridge Formation which overlies a prominent orange-weathering fault rock. Massive, meter-thick packages of sandstone are characterized by scoured bases, organic and carbonaceous debris, organic-rich lenses of mudstone and siltstone, and rare fining upwards sequences. Thin, less than 3 meter thick interbeds of organic rich mudstone and fine-grained sandstone contain plant stems, leaf impressions, and plant fragments. Conglomerate interbeds are less than 3 meters thick and are characterized by felsic plutonic clasts no larger than 25 cm. Conglomerates are exposed in the lowest 25 meters of the section where green weathering of sandstones and conglomerates is attributed to epidote and chlorite breakdown and alteration. The lowest 7 meters are highly indurated, orange and green weathered, and characterized by slickenlines in the basal sandstone. Note the detrital zircon age spectra from sandstone sample GP3 (Fig. 27) differs significantly from sample 04ATil9 (Bradley *et al.*, 2009) taken from the Hatcher Pass schist underlying the Arkose Ridge Formation strata at this location. See Figure 8 for map location and Figure 11 for explanation of symbols and units. n = total number of zircon grains.



Government Peak (GP)
120 m
105 m
90 m
75 m
60 m
45 m
30 m
15 m
0 m
fault rock zone
Hatcher Pass schist
clay
f
c
peb.
bld.
Relative probability
062711GP3
n = 79
40
240
440
640
840
1040
Age (Ma)
04ATil09
(Bradley et al, 2009)
n = 59
40
240
440
640
840
1040
Age (Ma)

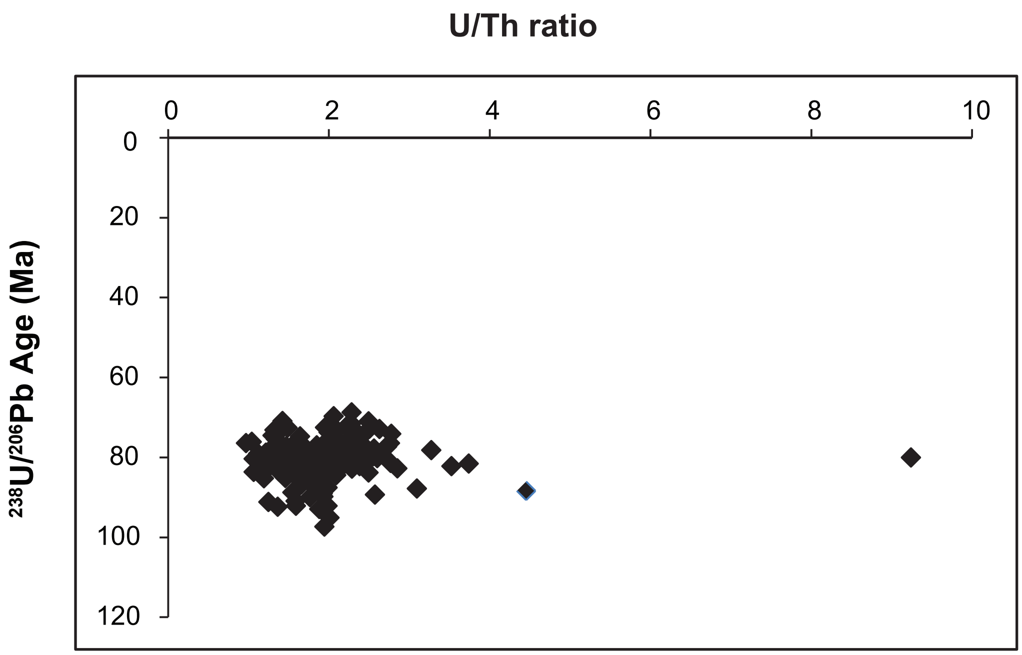


Figure 29. U/Th vs. U/Pb age of spot analyses of 160 detrital zircon grains from two sandstone samples at Government Peak. Note all detrital zircons yield <10 U/Th ratio indicating zircons are exclusively igneous in origin (Gehrels, 2012).

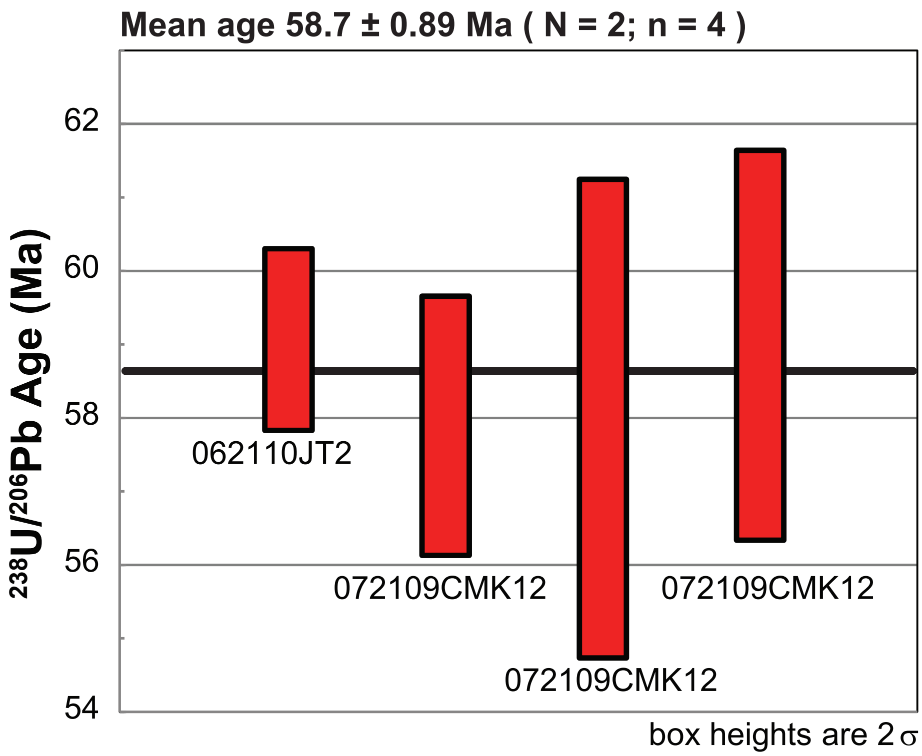


Figure 30. Age histograms of four youngest U/Pb ages from detrital zircons in Willow Creek sandstone samples from the southwestern Talkeetna Mountains. Plots show individual spot analyses from separate zircon grains from samples 071009CMK12 and 062110JT2. Ages with 2σ errors are plotted. The mean U-Pb age of the youngest three or more concordant detrital zircon grains (represented by black bar) that overlap in age at 2σ, has been shown to be more statistically robust than other methods, including (a) youngest single grain age, (b) youngest graphical age peak controlled by more than one grain age, and (c) mean age of the youngest two or more grains that overlap in age at 1σ (Dickinson and Gehrels, 2009). See Figure 5 for sample locations.

DISCUSSION

Stratigraphic Correlation

Sedimentological analysis of Paleogene strata exposed along Willow Creek indicates sediment was deposited by debris flow, hyperconcentrated flow, and streamflow on high-gradient gravelly braided stream systems influenced by episodic effusive volcanic eruptions. Lithologically similar alluvial-fluvial Arkose Ridge Formation strata crop out along strike in the southern Talkeetna Mountains between Willow Creek and Box Canyon (Fig. 3; Kortyna, 2011). Recent studies document the stratigraphy, sedimentology, geochronology, paleontology, and provenance of four especially thick and well exposed sections (Kortyna *et al*., 2009; Kassab *et al*., 2009; Kortyna, 2010; Sunderlin *et al*., 2011; Idleman *et al*., 2011). At all locations an unconformity separates Arkose Ridge Formation strata from underlying Jurassic–Cretaceous granitoid plutons and minor volcanic rocks. A low-precision K-Ar age is reported to be 56.2 ± 1.7 Ma from a lava interbed at Willow Creek (Silberman and Grantz, 1984). Similar maximum depositional ages during the Eocene (57–59 Ma) and 61–56 Ma ages from tuffs and lavas (Idleman *et al*., 2011) support deposition of the Willow Creek strata during the same time as the Arkose Ridge Formation strata. Comparison of detrital spectra from Willow Creek sandstones to other Arkose Ridge Formation sandstone in the southern Talkeetna Mountains yields similar dominant age populations of Late Cretaceous to Paleocene ages (60–100 Ma) and subordinate Early Cretaceous to Jurassic ages (200–100 Ma). Based on these data, the Willow Creek strata represent the westernmost outcrop of Arkose Ridge Formation, extending the western boundary of the Matanuska Valley-Talkeetna Mountain forearc basin from Arkose Ridge to Willow Creek (Fig. 3). The combination of provenance and sedimentological data from these five Arkose Ridge Formation sections allows for a detailed discussion on how source terranes, sediment transport pathways, and depositional environments vary along strike within the forearc basin during a well-documented episode of spreading ridge subduction.

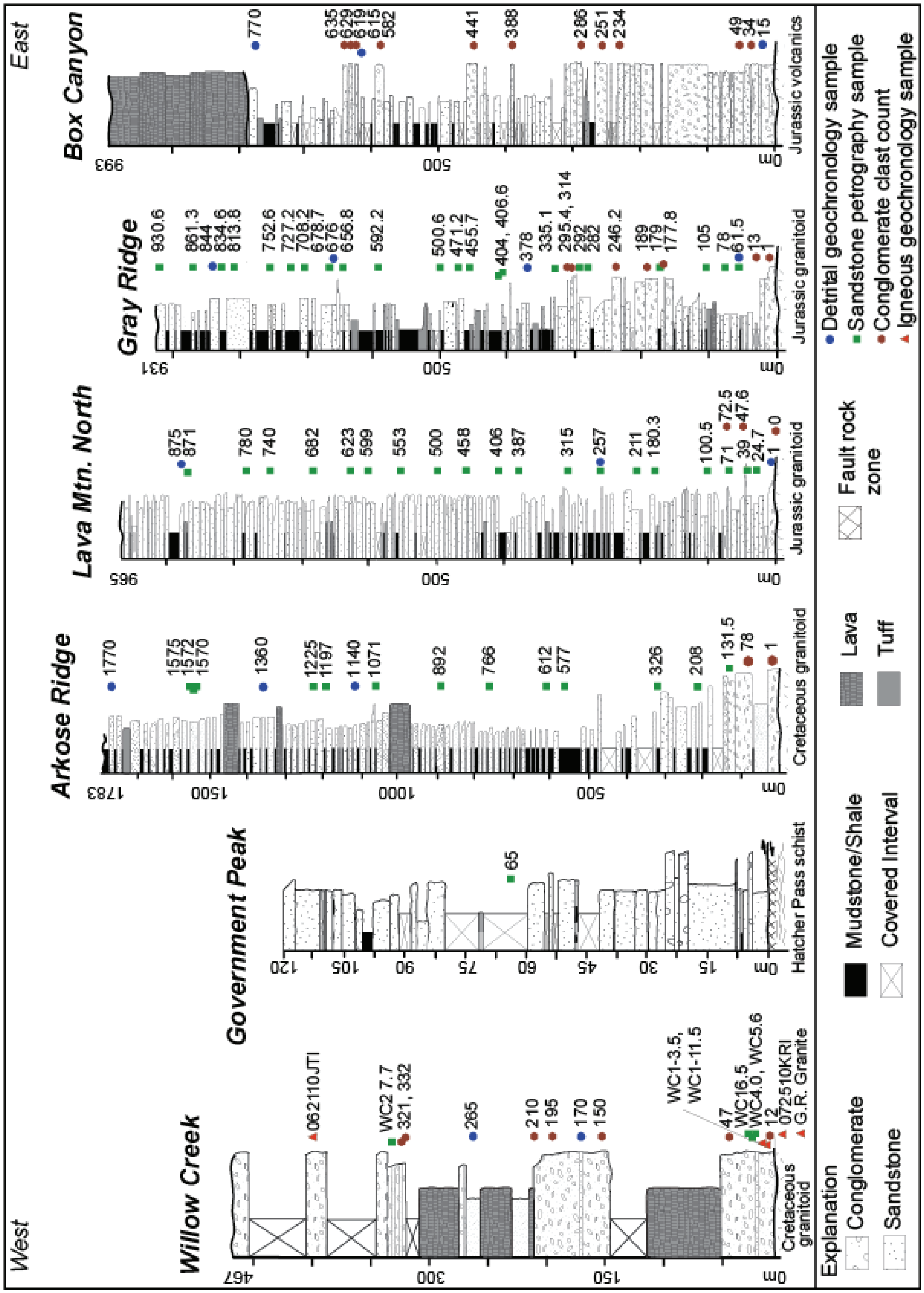
Inferred Depositional Environments

Depositional environments will first be interpreted from new detailed sedimentological observations of Willow Creek strata and then discussed in context of Arkose Ridge Formation strata in the southern Talkeetna Mountains. The Willow Creek section was deposited within a drainage basin located along the northwestern margin of the Matanuska Valley-Talkeetna Mountain forearc basin adjacent to remnant continental-arc plutons. Strata are characterized by massive, pebble-boulder conglomerate (54% of exposed strata along Willow Creek) that alternate with aphanitic, mafic lava (38%) and cross stratified arkosic sandstone (8%). Overall coarseness and poor sorting of these strata indicate deposition proximal to local source terranes. Dominance of cobble-sized clasts in the conglomerates (Tables 1 and 2) are characteristic of stream-dominated alluvial slopes (Collinson, 1986), also referred to as humid alluvial fans (Fraser and Suttner, 1986). Matrix to clast supported, cobble-boulder conglomerates (Lithofacies Association 1, FA1) record deposition by debris and hyperconcentrated flood flows, whereas massive to imbricated, pebble-cobble conglomerate (FA2) and lenticular bedded, cross stratified sandstone (FA3) document deposition by normal stream-flow conditions

(Prothero and Schwab, 2004). Episodic effusive eruptions from proximal eruptive centers prompted deposition of aphanitic, mafic lavas (FA4) directly upon braided stream deposits. Lithofacies analyses of Willow Creek strata and interbedded lavas support the interpretation of a depositional environment characterized by debris flows, hyperconcentrated flood flow, stream flow, and effusive volcanic eruptions on a high-gradient, braided stream system.

Strata correlative in age to strata exposed along Willow Creek crop out along strike in the southern Talkeetna Mountains for 90 km between Willow Creek in the west to Box Canyon in the east (Fig. 3). Comparison of generalized measured stratigraphic sections from each study area provides insight on along-strike changes in depositional conditions and environments (Fig. 31). Overall, the fluvia-alluvial Arkose Ridge Formation strata exposed in the southern Talkeetna Mountains are grossly similar in lithology to strata exposed at Willow Creek. All sections are dominated by texturally and compositionally immature siliciclastic strata and subordinate volcanic interbeds. However, variations in alluvial-fluvial depositional styles suggest deposition of individual sections within separate drainage basins (Fig. 31). For example, Lava Mountain, Gray Ridge, and Box Canyon sections contain fine-grained lacustrine deposits that are not observed at Willow Creek or Arkose Ridge sections (Kassab *et al*., 2009; Kortyna *et al*., 2010). An abundance of lava interbeds are also documented only at Willow Creek, Arkose Ridge, and Box Canyon whereas the majority of tuffs are exposed at Lava Mountain and Gray Ridge. Thick successions of sandy braided river deposits not observed at Willow Creek crop out at Arkose Ridge, Lava Mountain, and Gray Ridge

Figure 31. Generalized stratigraphic sections measured through Willow Creek, Government Peak, Arkose Ridge, Lava Mountain, Gray Ridge, and Box Canyon. Stratigraphic sections are arranged from West (left) to East (right). A total of 23 clast counts (brown hexagons) were collected from conglomerate beds. A total of 54 sandstone petrography samples (green squares) were collected for modal analyses. U-Pb detrital zircon analyses were conducted on 15 sandstone samples (blue circles). Measured sections adapted from Trop *et al*. (2003), Kortyna *et al*. (2009), Kassab *et al.* (2009), and this study. Lithofacies and paleobotanical analyses demonstrate that strata were deposited in alluvial paleovalleys, anastomosing to braided fluvial systems, floodplain ponds and lakes, and tidally influenced streams. Willow Creek and Government Peak stratigraphic sections are from this study; other sections are from Kortyna (2011).


West
East
Willow Creek
Government Peak
Arkose Ridge
Lava Mtn. North
Gray Ridge
Box Canyon
Cretaceous granitoid
Hatcher Pass schist
Jurassic granitoid
Jurassic volcanics
Explanation
Conglomerate
Sandstone
Mudstone/Shale
Covered Interval
Lava
Tuff
Fault rock zone
Detrital geochronology sample
Sandstone petrography sample
Conglomerate clast count
Igneous geochronology sample

(Kassab *et al*., 2009; Kortyna *et al*., 2010). Generally, measured sections in the southern Talkeetna Mountains document a better degree of organization in beds containing a higher percentage of finer-grained sedimentary rocks such as mudstones, siltstones, and fine-to medium-grained sandstones in comparison to the Willow Creek section (Fig. 31).

In general, pebble-boulder conglomerate, sandstone, and mudstone of the Arkose Ridge Formation show a southward trend of decreasing grain size to mostly mudstone and subordinate coal and sandstone of the Chickaloon Formation south of the Castle Mountain Fault (Fig. 3; Winkler, 1992; Trop *et al.*, 2003). This lithofacies trend is consistent with southward-directed paleoflow indicators that are characteristic of the Arkose Ridge Formation, suggesting sediment was derived from the north of the forearc basin from the remnant magmatic arc (Fig. 32). Conversely, geologic mapping and detailed sedimentological observations of the southernmost strata of the Chickaloon Formation in the northern Chugach Mountains along the Border Ranges Fault (Fig. 1) document coarse-grained sandstones and conglomerates with north-directed paleocurrent indicators (Fig. 19). These units are interpreted to be deposited by northward-prograding gravelly alluvial fans and document erosion of the accretionary prism (Little, 1988; Trop *et al.*, 2003), providing evidence for a double-sided forearc basin. The fluvial-alluvial systems prograding from the northern and southern margins of the forearc basin are interpreted to discharge into a south-west flowing axial stream system in the central region of the basin (Fig. 32). The following section discusses in detail how unique variations in provenance data at each section further supports deposition of Arkose Ridge

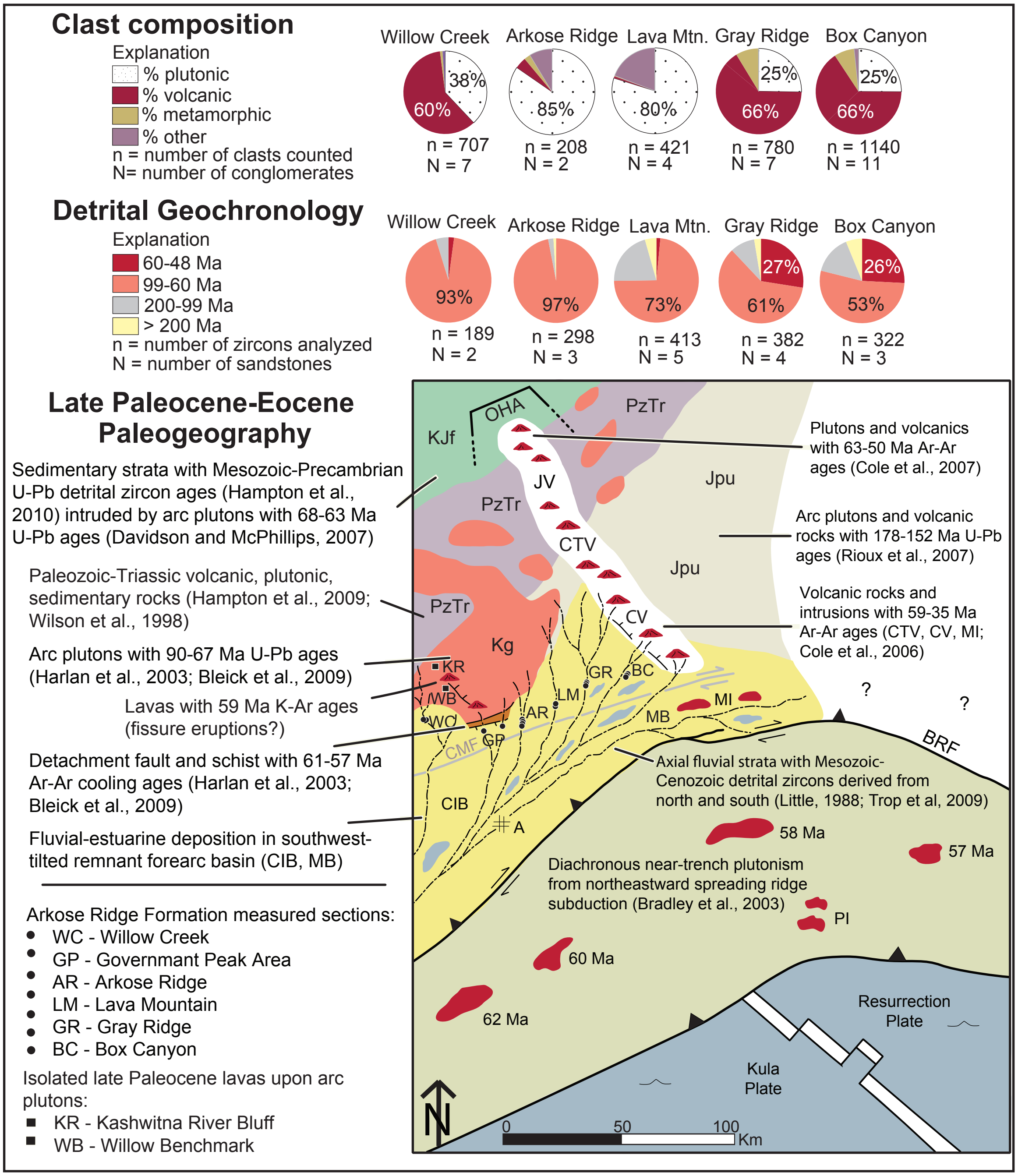
Formation sections in separate drainage basins that are part of a larger axial stream system.

Sedimentary Provenance Interpretation

Plutonic and Quartzofeldspathic Provenance

This section will first discuss interpretations for sedimentary provenance data at Willow Creek followed by discussion of the significance of these interpretations in context of provenance data collected from Arkose Ridge Formation sections in the southern Talkeetna Mountains. New compositional and geochronologic data from the Arkose Ridge Formation at Willow Creek suggest plutonic and volcanic detritus was eroded from local igneous rocks exposed in the southwestern Talkeetna Mountains, including Paleogene mafic volcanic rocks (Silberman and Grantz, 1984) and Cretaceous granitic plutons of the late Cretaceous–Paleocene Alaska Range-Talkeetna magmatic arc (90–67 Ma; Bleick *et al.*, 2009). Derivation of Arkose Ridge Formation sediment from local northern source terranes is supported by sediment transport directions that document southeast-, south-, and southwestward paleoflow (Fig. 19). The main detrital zircon age populations (85–60 Ma and 100–85 Ma; 95% of analyzed grains) from two Willow Creek sandstone samples correlate with the Cretaceous–Paleocene age of the Willow Creek pluton exposed in the southwesternmost Talkeetna Mountains. Clast composition data also documents an abundance of felsic plutonic and mafic volcanic clasts in conglomerates exposed at Willow Creek (Fig. 20). The plutonic clasts are similar in texture and mineralogy to the underlying granitoid exposed at the base of the

Figure 32. Paleogeographic reconstruction during late Paleocene-Eocene time. Black circles represent measured stratigraphic sections from the Arkose Ridge Formation with detrital geochronologic samples. Western fluvial environments deposited chiefly plutonic detritus eroded from Cretaceous-Paleocene arc plutons exposed along the northwestern margin of the basin, with exception of the Willow Creek strata. The Willow Creek conglomerate is composed of a high percentage of volcanic clasts in comparision to plutonic clasts dominating the conglomerates of Arkose Ridge and Lava Mountain. Eastern fluvial-lacustrine environments deposited a higher proportion of coeval volcanic detritus eroded from the Caribou Creek volcanic center (CV). Abbreviations are as follows: Paleogene sedimentary basins: MB-Matanuska basin; CIB-Cook Inlet basin. Major Paleogene volcanic belts: CTV-Central Talkeetna Mountains volcanics; JV-Jack River volcanics. Faults: CMF-Castle Mountain fault; BRF-Border Ranges fault. Intrusive igneous rocks: MI-Matanuska intrusives; OHA-Oroclinal hinge of Alaska; PI-Prince William sound intrusives. #A-City of Anchorage. Pie diagrams summarizing conglomerate clast count and detrital age data for Willow Creek (this study) as well as correlative conglomerates exposed at Arkose Ridge, Lava Mountain, Gray Ridge, and Box Canyon. See Figure 3 for explanation of geologic map units. Adapted from Kortyna (2011).



Clast composition
Explanation
% plutonic
% volcanic
% metamorphic
% other
n = number of clasts counted
N= number of conglomerates
Willow Creek
Arkose Ridge
Lava Mtn.
Gray Ridge
Box Canyon
38%
60%
n = 707
N = 7
85%
n = 208
N = 2
80%
n = 421
N = 4
25%
66%
n = 780
N = 7
25%
66%
n = 1140
N = 11
Detrital Geochronology
Explanation
60-48 Ma
99-60 Ma
200-99 Ma
> 200 Ma
n = number of zircons analyzed
N = number of sandstones
Willow Creek
Arkose Ridge
Lava Mtn.
Gray Ridge
Box Canyon
93%
n = 189
N = 2
97%
n = 298
N = 3
73%
n = 413
N = 5
27%
61%
n = 382
N = 4
26%
53%
n = 322
N = 3
Late Paleocene-Eocene Paleogeography
Sedimentary strata with Mesozoic-Precambrian U-Pb detrital zircon ages (Hampton et al., 2010) intruded by arc plutons with 68-63 Ma U-Pb ages (Davidson and McPhillips, 2007)
Paleozoic-Triassic volcanic, plutonic, sedimentary rocks (Hampton et al., 2009; Wilson et al., 1998)
Arc plutons with 90-67 Ma U-Pb ages (Harlan et al., 2003; Bleick et al., 2009)
Lavas with 59 Ma K-Ar ages (fissure eruptions?)
Detachment fault and schist with 61-57 Ma Ar-Ar cooling ages (Harlan et al., 2003; Bleick et al., 2009)
Fluvial-estuarine deposition in southwest-tilted remnant forearc basin (CIB, MB)
Arkose Ridge Formation measured sections:
WC - Willow Creek
GP - Governmant Peak Area
AR - Arkose Ridge
LM - Lava Mountain
GR - Gray Ridge
BC - Box Canyon
Isolated late Paleocene lavas upon arc plutons:
KR - Kashwitna River Bluff
WB - Willow Benchmark
KJf
OHA
PzTr
JV
PzTr
CTV
Jpu
Jpu
PzTr
Kg
CV
KR
WB
WC
GP
AR
LM
GR
BC
MB
MI
CMF
CIB
A
BRF
?
?
Plutons and volcanics with 63-50 Ma Ar-Ar ages (Cole et al., 2007)
Arc plutons and volcanic rocks with 178-152 Ma U-Pb ages (Rioux et al., 2007)
Volcanic rocks and intrusions with 59-35 Ma Ar-Ar ages (CTV, CV, MI; Cole et al., 2006)
Axial fluvial strata with Mesozoic-Cenozoic detrital zircons derived from north and south (Little, 1988; Trop et al, 2009)
58 Ma
57 Ma
Diachronous near-trench plutonism from northeastward spreading ridge subduction (Bradley et al., 2003)
PI
60 Ma
62 Ma
Resurrection Plate
Kula Plate
N
0
50
100
Km

Willow Creek section suggesting erosion of the basal granitoid. Both detrital samples document a peak age population (72–73 Ma) on detrital zircon age spectra (Fig. 25) matching the U-Pb age of the underlying granitoid at Willow Bench (71.2 ± 2.1 Ma), Willow Creek (72.0 ± 1.4, 73.5 ± 1.4 Ma; Fig. 21) and samples collected farther east in the Willow Pluton (77–75 Ma; Bleick *et al*., 2009; Harlan *et al*., 2003). Two granitoid clasts were collected from FA1 conglomerate near the base of the Willow Creek section (Fig. 10). One clast yields Late Cretaceous ages of 73.6 ± 1.2 Ma and overlaps the age of the underlying granitoid pluton. The second clast yields ages of 85.8 ± 2.0 Ma and overlaps subordinate detrital zircon age populations from Willow Creek sandstones (Fig. 33). The absence of zircon ages from both the granitoid clasts and Willow Creek detrital spectra that overlap the 86–79 Ma ages of the granitoid underlying the Government Peak area suggests a different plutonic source terrane that supplied detritus. The plutonic source terrane is likely an unrecognized or completely eroded Cretaceous phase of plutonism in the Willow Creek area. The abundance of feldspar, quartz, and plutonic lithic grains and minor volcanic lithic grains in sandstone thin sections further supports erosion of felsic plutonic and volcanic source terranes (Fig. 21).

Subordinate Early Cretaceous to Jurassic detrital zircon ages (200–100 Ma; 5% of total analyzed grains) indicate an older source terrane supplying minor detritus to the Arkose Ridge Formation (Fig. 25). This older age population is dominated by zircon ages of 108 to 115 Ma (78% of 9 total grains; Table 7) and two outlier zircon ages of 194 and 189 Ma. Jurassic plutons of the Talkeetna magmatic arc crop out extensively in the southern Talkeetna Mountains and Alaska Peninsula but are not recognized in modern surficial outcrops north of Willow Creek. Given the inferred proximity of deposition based on sedimentological data, Jurassic detrital zircons are interpreted as recording erosion of unrecognized or completely eroded Jurassic aged plutonic source terranes north of the Willow Creek section. Jurassic plutons may also be exposed north of Willow Creek in the subsurface of the Susitna basin. The Jurassic–Cretaceous Kahiltna Assemblage exposed in the northern Talkeetna Mountains represents a potential distal source for 200–100 Ma zircon ages. However, most detrital age spectra in the Kahiltna also include Paleozoic–Precambrian ages (Hampton *et al.*, 2007) and strata contain sedimentary lithic and rounded monocrystalline quartz grains (Trop, 2008), which are not observed in the Willow Creek detrital age spectra or strata, suggesting sediment derivation from mainly local source terranes.

A granitoid clast collected from the top of the generalized Willow Creek measured section (Fig. 10) yields a range of Latest Triassic to Early Jurassic U-Pb zircon ages (215–190 Ma; Fig. 23). This age range is significantly different than the subordinate 115–114 Ma age population observed in Willow Creek detrital age spectra, suggesting an even older plutonic source terrane supplying detritus to the Willow Creek section (Fig. 33). Two units mapped at the western margin of the Talkeetna Mountain batholith in the central Talkeetna Mountains 64 km northeast of Willow Creek represents the closest potential source terranes for the Early Jurassic granitoid clast and sparse Early Jurassic detrital zircons in sandstone. The first unit, a granodioritic pluton, yielded highly discordant thermal ionization mass spectrometry (TIMS) U-Pb zircon ages and five

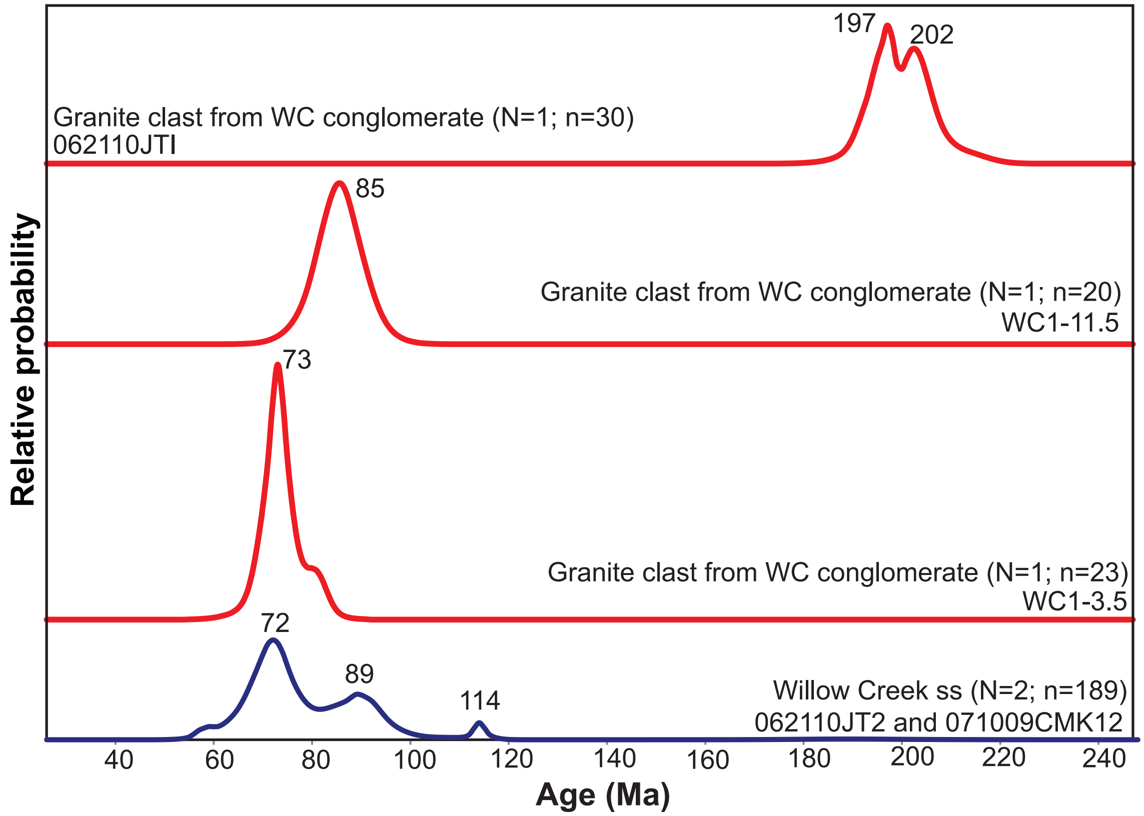


Figure 33. Age probability plots showing distribution of U-Pb age determinations for detrital zircon grains from Willow Creek sandstones (blue) and granitoid clasts (red) from Willow Creek conglomerate facies association one (FA1). Ages represent individual spot analyses from separate detrital zircon grains. U-Pb ages are plotted as a normalized relative-probability distribution (Ludwig, 2003). Relative heights of peaks correspond to statistical significance. Note that age population of granitiod clasts overlap the age populations observed in the Willow Creek sandstone. The Jurassic age population overlaps with sparse detrital zircons in the Willow Creek sandstone signature, but those peaks are not visible at this scale. There are two Jurassic detrital zircon grains (Sample 062110JT2, 189 Ma; 071009CMK12, 194 Ma) from the Willow Creek sandstone that correlate to the Jurassic aged granitiod clast (Fig. 25). See Figure 5 for sample locations on geologic map. Abbreviations: WC-Willow Creek. N = total number of samples, n = total number of zircon grains.

concordant LA-ICP-MS spot analyses with a cluster of zircon ages at 190.5 ± 6.8 (n = 4; Rioux *et al*., 2007). A second unit, consisting of intermingled plutons, yielded a spread of TIMS ages between 193–190 Ma and LA-ICP-MS zircon ages of 187.4 ± 2.2 Ma (n = 44, outliers at 232.0 ± 17.0 and 209.1 ± 22.8 Ma Ma; Rioux *et al*., 2007) for one sample and 191.1 ± 3.4 Ma for the second (n = 44, maximum spot age 226.3 ± 7.6 Ma; Rioux *et al*., 2007). Thus, the Late Triassic to Early Jurassic granitoid clast contained in the Arkose Ridge Formation may indicate erosion and long-distance transport from the Late Triassic to Early Jurassic granitoid pluton in the central Talkeetna Mountains or shorter distance transport from part of the pluton that has been completely eroded or subsequently covered by Cenozoic strata in the subsurface of the Susitna basin.

Both Willow Creek detrital sandstone samples yield nearly identical detrital zircon spectra dominated by Cretaceous ages (Fig. 25). The significant change from stratigraphically lower strata, dominated by Cretaceous aged detritus, to the presence of a Triassic–Jurassic aged clast near the top of the section, suggests a potential upsection shift in provenance to include a greater proportion of Jurassic aged detritus (Fig. 10). However, further U-Pb geochronologic analyses of granitoid clasts throughout the section and of the uppermost sandstones are needed to evaluate this hypothesis on possible upsection provenance changes. The combination of provenance data and paleocurrent measurements at Willow Creek suggests sediment derivation from dominantly Cretaceous plutons of the Alaska Range-Talkeetna magmatic arc plutons and Paleogene mafic lavas mapped in the southwestern Talkeetna Mountains and Susitna basin subsurface (Fig. 32).

Comparison of provenance data between Willow Creek and Arkose Ridge Formation sections in the southern Talkeetna Mountains documents change in provenance along strike of the Matanuska-Talkeetna forearc basin (Table 7). All analyzed grains from the Arkose Ridge Formation in the southern Talkeetna Mountains document U/Th ratios < 10 (Fig. 34). The western Arkose Ridge Formation strata at the Government Peak area yield a peak detrital zircon population ca. 79 Ma that overlaps with the age of the adjacent and newly dated Cretaceous intrusion (81.0 ± 1.4 Ma) at that location (Fig. 27). The age of this pluton is ca. 8 to 10 Ma older than the pluton exposed 5 km north of Government Peak and underlying the Willow Creek section. The majority of individual zircon ages are between 85–75 Ma (73% of all analyzed grains), creating a significantly different U-Pb peak age population in comparison to Willow Creek peak detrital ages. This indicates the local underlying pluton was the main source of detritus to the Government Peak area (Fig. 35). The remaining 27% of the detrital population is characterized by 74–68 Ma (13% of all analyzed grains) and 97–86 Ma (15%) ages, indicating minor detritus was supplied from the 72 Ma Willow pluton exposed to the north. The 97–86 Ma age population suggests possible erosion of the same unmapped source terrane that supplied the 89–88 Ma detritus to the Willow Creek section. The age spectra of zircons from the granitoid at the Government Peak area do not overlap with the 89–88 Ma ages of zircons from sandstone and granitoid clasts at Willow Creek, suggesting there is a proximal unmapped, unexposed, or completely eroded 89–88 Ma plutonic source terrane that supplies detritus to Willow Creek. The western Arkose Ridge Formation strata at Arkose Ridge and Lava Mountain in the southern Talkeetna

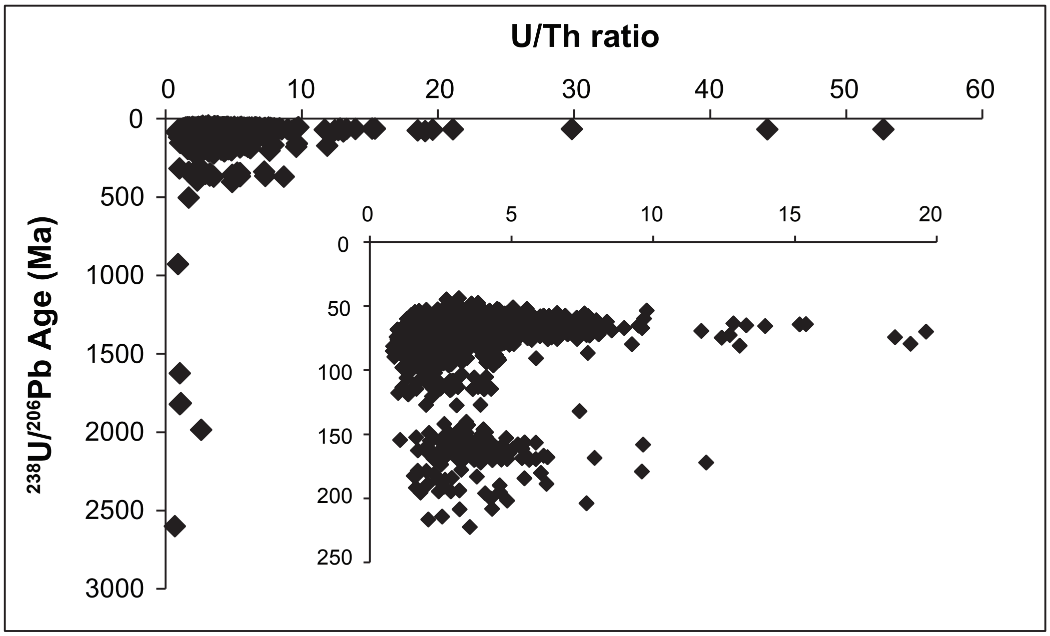


Figure 34. U/Th vs. U/Pb age of spot analyses of 1765 detrital zircons from 19 sandstone samples of the Arkose Ridge Formation from this study and Kortyna (2011). Note that >98% of zircons are <200 Ma and >99% of zircons have <10 U/Th ratios. Inset shows details for grains <250 Ma and <20 U/Th.

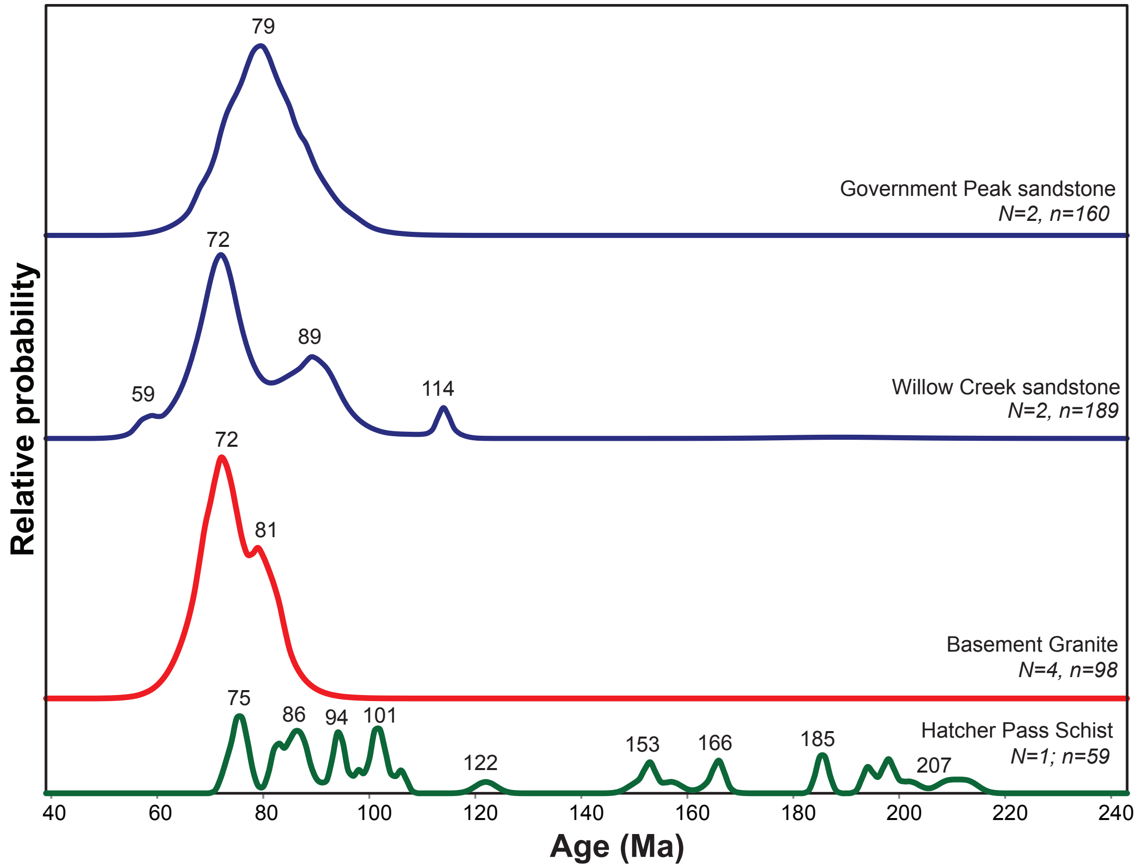


Figure 35. Age probability plots showing distribution of U-Pb age determinations for detrital zircon grains from the Hatcher Pass schist (green), the granitoid pluton underlying the Willow Creek section and Willow Bench (red), the Willow Creek sandstone (blue), and the Government Peak sandstone (blue). Ages represent individual spot analyses from separate detrital zircon grains. U-Pb ages are plotted as a normalized relative-probability distribution (Ludwig, 2003). Relative heights of peaks correspond to statistical significance. In order to display age population relationships between samples, 22 grains older than 240 Ma are excluded from the Hatcher Pass Schist probability plot (7 Paleozoic grains, 302-471 Ma; 15 Precambrian grains, 1016-2692 Ma). Note > 140 Ma populations (153-2692 Ma) in the Hatcher Pass Schist not represented in either the Willow Creek or Government Peak sandstone. N = number of samples, n = total number of zircon grains. See Figure 4 for sample locations on geologic map.

Mountains yield a main detrital zircon age population (90–67 Ma) overlapping with the Cretaceous aged pluton to the north. The detrital zircon age spectra from Arkose Ridge and Lava Mountain have similar signatures to the Willow Creek section, indicating that the Cretaceous pluton to the north was the main source of detritus for the western Arkose Ridge Formation strata (Fig. 36). Sandstone petrography documents high percentages of quartz, feldspar, and plutonic lithic grains (Kortyna, 2011) at both Arkose Ridge and Lava Mountain. These interpretations are further supported by the shared abundance of felsic plutonic clasts in conglomerates at Lava Mountain, Arkose Ridge, and Willow Creek (Fig. 31).

Although the detrital age populations and abundance of plutonic clasts at Willow Creek are similar between Arkose Ridge and Lava Mountain (Table 7), the composition of detritus significantly differs. Conglomerates at Willow Creek are dominated by volcanic clasts, but plutonic clasts are also present (Fig. 20). This is in contrast to conglomerates dominated by plutonic clasts at Arkose Ridge and Lava Mountain. The distinct shift in detritus composition from Arkose Ridge to Willow Creek documents a major change in provenance to include sediment derivation from both volcanic and plutonic terranes exposed in the southwestern Talkeetna Mountains, including Willow Bench and Kashwitna River Bluff. Willow Creek, Arkose Ridge, and Lava Mountain have a very similar main detrital zircon age population (73–70 Ma), but the detrital age spectra exhibit variations in secondary age populations (Fig. 36). Lava Mountain strata contain abundant 200–99 Ma grains and >200 Ma grains not documented at Arkose Ridge and Willow Creek (Table 7). Willow Creek also shows detrital age peaks at 88 Ma and 114 Ma not documented at Arkose Ridge or Lava Mountain (Fig. 36). The slight variations in provenance data in the western Arkose Ridge Formation sections support deposition of sediment in separate drainage basins that primarily drained Cretaceous plutonic bedrock but included variable secondary source terranes (Fig. 32).

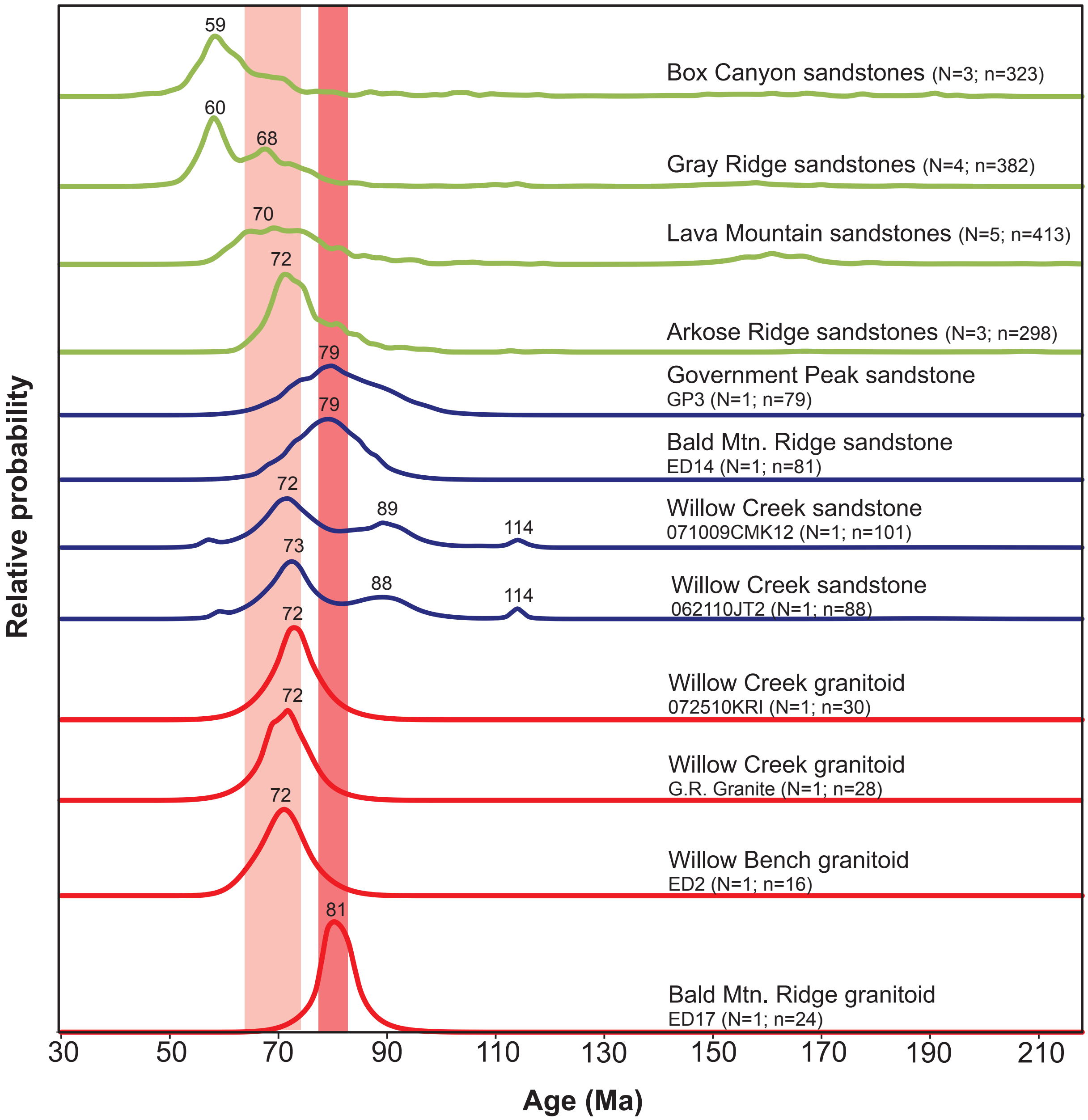
Detrital zircon ages vary even more significantly when comparing Willow Creek with the eastern Arkose Ridge Formation sections (Table 7). Detrital ages from Lava Mountain, Gray Ridge, and Box Canyon document a significant 200–99 Ma age population (Fig. 36), indicating the Jurassic Talkeetna magmatc arc plutons (177–157 Ma) were major sources of detritus for the eastern Arkose Ridge Formation strata (Fig. 32). The increase in Cretaceous zircon ages and general absence of Jurassic zircons at both Arkose Ridge and Willow Creek (Fig. 36) documents the shift in provenance from the Cretaceous to Jurassic plutons from west to east (Fig. 32). Eastern Arkose Ridge Formation strata at Gray Ridge and Box Canyon in the southern Talkeetna Mountains document a significant Paleocene–Eocene age peak (60–59 Ma) in detrital zircon age spectra (Fig. 36) and high percentages of volcanic lithic grains in sandstone thin sections (Kortyna, 2011). This age population matches the age of the Caribou Creek volcanic center which crops out east of the Arkose Ridge Formation (59–36 Ma; Cole *et al.,* 2006). These age populations indicate the Caribou Creek volcanic center was a major source of detritus for the eastern outcrops of Arkose Ridge Formation, which is further supported by the high abundance of volcanic clasts in conglomerates and sandstones at Box Canyon and Gray Ridge (Fig. 32). Plutonic clasts present at Box Canyon and Gray Ridge are interpreted to be derived from the plutons exposed to the north in the

Cretaceous–Paleocene Alaska Range-Talkeetna Mountains belt and the Jurassic Talkeetna magmatic arc (Kortyna, 2011). The absence of volcanic clasts and volcanic lithic grains in sandstones at Lava Mountain and Arkose Ridge indicates a major shift in source terranes from eastern sections to the western sections of Arkose Ridge Formation in the Talkeetna Mountains (Kortyna, 2011). Despite this westward decrease of volcanic material in the Arkose Ridge Formation, conglomerate clast composition data collected at Willow Creek appear to be most similar to data sets collected at localities furthest to the east (Gray Ridge and Box Canyon) which contain high percentages of volcanic clasts. However, the volcanic clasts at Willow Creek are inferred to have been derived from more localized volcanic sources that are proximal to Willow Creek (e.g., BENCH and KASH on Fig. 6) and consist of mafic volcanics contrary to felsic varieties at Box Canyon and Gray Ridge. The nature of the volcanic field will be described in more detail in the next section.

Volcanic Provenance

High percentages of lava (K-Ar age of 56.2 ± 1.7 Ma; Silberman and Grantz, 1984) exposed along Willow Creek, the presence of volcanic lithic grains in sandstones (Fig. 21), and the abundance of volcanic clasts in conglomerates (60%; Fig. 20) distinguishes this section from the other western Arkose Ridge Formation sections at Arkose Ridge and Lava Mountain. The strata exposed north of Willow Creek at the Kashwitna River Bluff and Willow Bench document thick packages of Paleogene mafic lava flows (K-Ar age of 51.8 ± 1.6 Ma; Silberman and Grantz, 1984) directly overlying granitoid (Fig. 6). Given their localized areal extent, lack of spatially associated plutons,

Figure 36. Age probability plots showing distribution of U-Pb age determinations for detrital zircon grains from Arkose Ridge Formation sandstones (blue, this study; green, previous studies by Kortyna (2011) and granitoid plutons (red) at Willow Creek, Willow Bench, and Bald Mountain Ridge. Samples are arranged from east (top) to west (bottom). Ages represent individual spot analyses from separate detrital zircon grains. U-Pb ages are plotted as a normalized relative-probability distribution (Ludwig, 2003). Relative heights of peaks correspond to statistical significance. Pink bar denotes 65-74 Ma age range of the Willow Creek Cretaceous pluton (TKg on Fig. 3; Winkler, 1992; Harlan *et al*., 2003; this study). Red bar denotes 78-83 Ma age range of the Bald Mountain Ridge granitoid (this study). N = number of samples, n = total number of zircon grains. See Figure 3 for sample locations on geologic map.



59
Box Canyon sandstones (N=3; n=323)
60
68
Gray Ridge sandstones (N=4; n=382)
70
Lava Mountain sandstones (N=5; n=413)
72
Arkose Ridge sandstones (N=3; n=298)
79
Government Peak sandstone
GP3 (N=1; n=79)
79
Bald Mtn. Ridge sandstone
ED14 (N=1; n=81)
72
89
114
Willow Creek sandstone
071009CMK12 (N=1; n=101)
73
88
114
Willow Creek sandstone
062110JT2 (N=1; n=88)
72
Willow Creek granitoid
072510KRI (N=1; n=30)
72
Willow Creek granitoid
G.R. Granite (N=1; n=28)
72
Willow Bench granitoid
ED2 (N=1; n=16)
81
Bald Mtn. Ridge granitoid
ED17 (N=1; n=24)
30 50 70 90 110 130 150 170 190 210
Age (Ma)
Relative probability

Table 7. Summary of detrital ages for sandstone samples of the Arkose Ridge Formation

Period	Late Paleocene-Eocene	Latest Cretaceous-Early Paleocene	Early Late Cretaceous	Early Cretaceous-Jurassic	Triassic	Devonian-Mississippian	Cambrian	Precambrian	
Age (Ma)	60-48 Ma	85-60	100-85	200-100	251-200	416-318	488-542	>542 Ma	Total
Summary of detrital ages from Willow Creek (N=2)									
# grains	4	119	57	9	0	0	0	0	189
%	2.1%	63.0%	30.1%	4.8%	0.0%	0.0%	0.0%	0.0%	100.0%
Summary of detrital ages from Government Peak Area (N=2)									
# grains	0	132	28	0	0	0	0	0	160
%	0.0%	83.1%	16.9%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Summary of detrital ages from Arkose Ridge (N=3)									
# grains	0	263	27	7	1	0	0	0	298
%	0.0%	88.3%	9.1%	2.3%	0.3%	0.0%	0.0%	0.0%	100.0%
Summary of detrital ages from Lava Mountain and Sheep Valley (N=5)									
# grains	6	280	31	87	5	3	0	1	413
%	1.5%	67.8%	7.5%	21.1%	1.2%	0.7%	0.0%	0.2%	100.0%
Summary of detrital ages from Gray Ridge (N=4)									
# grains	128	207	6	36	0	4	0	1	382
%	33.5%	54.2%	1.6%	9.4%	0.0%	1.0%	0.0%	0.3%	100.0%
Summary of detrital ages from Box Canyon(N=3)									
# grains	110	135	13	48	1	11	1	4	323
%	34.1%	41.8%	4.0%	14.9%	0.3%	3.4%	0.3%	1.2%	100.0%
Summary of detrital ages from all Arkose Ridge Formation samples (N=19)									
# grains	248	1136	162	187	7	18	1	6	1765
%	14.1%	64.4%	9.1%	10.6%	0.40%	1.0%	0.06%	0.34%	100.0%

Notes: N = number of samples analyzed. See Figure 3 for sample locations. Willow Creek and Government Peak area detrital ages are reported in this st others from Kortyna (2011).

and subdued physiographic expression (Fig. 7), these outcrops are tentatively interpreted to represent fissure eruptive centers along normal faults related to extensional deformation. Compositional, paleocurrent, and sedimentologic data indicate that these local eruptive centers likely represent the volcanic source terrane that provided mafic volcanic clasts in conglomerates and lavas at Willow Creek. Episodic fissure eruptions would result in lavas flowing south and likely westward into the Susitna basin from Kashwitna River Bluff and Willow Bench, resulting in deposition onto the proximal stream-dominated alluvial slope at Willow Creek. The lack of pillow structures in lava, hyaloclastites, or peperites suggests deposition did not occur in subaqueous settings (ponds or lakes).

Similar to the Willow Creek section, thick packages of lava are well-exposed in the uppermost section at Box Canyon located at the eastern forearc basin margin adjacent to the Caribou Creek Volcanic Center (Fig. 3). The upsection increase in volcanic-lithic grains in sandstones, volcanic clasts in conglomerates, and interbedded lava flows is consistent with syndeposition of Arkose Ridge Formation at Box Canyon with the development of the Caribou Creek volcanic center (Kortyna, 2011). Measured sections located east of Willow Creek at Arkose Ridge, Lava Mountain, and Gray Ridge document a paucity of interbedded lava flows, consistent with increased distance from both the inferred fissure eruptive centers north of Willow Creek and the Caribou Creek Volcanic Center to the east (Fig. 31). Box Canyon and Gray Ridge sections document an abundance of volcanic-lithic grains in sandstones derived from the Caribou Creek Volcanic Center (Kortyna, 2011). Due to the distance between Willow Creek and the

Caribou Creek Volcanic Center (~ 90 kilometers) and lack of volcanic detritus at Arkose Ridge and Lava Mountain, it is improbable that the Caribou Creek Volcanic Center supplied detritus to the Willow Creek section. This suggests at least two main volcanic source terranes were supplying sediment to the Arkose Ridge Formation: the Caribou Creek Volcanic Center supplying detritus to eastern sections and the Willow Bench/Kashwitna River Bluff area supplying detritus to western sections (Fig. 32).

It is important to note that the ages of Paleocene–Eocene volcanic sources are not common in detrital age populations at Willow Creek. Unlike Box Canyon and Gray Ridge, which received sediment from zircon-rich felsic volcanic rocks including rhyolite domes at the Caribou Creek volcanic center (Cole *et al.*, 2006), Willow Creek was sourced by mafic basalts not expected to yield zircon. There are no documented felsic volcanic sources at either the Willow Bench or Kashwitna River Bluff, resulting in the absence of felsic volcanic conglomerate clasts and only sparse Paleogene detrital age populations at Willow Creek.

Metamorphic Provenance

The presence of metamorphic fragments in sandstone thin sections indicates a minor, non-igneous source terrane to the Arkose Ridge Formation. Metamorphic fragments in sandstone thin sections consist primarily of mica schist (Fig. 21). At Hatcher Pass, biotite schist with 75 Ma and older detrital zircons crops out approximately 20 km east of the Willow Creek section (Bradley *et al.*, 2009), representing a potential metamorphic source terrane for the Arkose Ridge Formation (Fig. 32). The schist was deposited and metamorphosed during latest Cretaceous–Paleocene time based on the youngest cluster of detrital zircons (77–75 Ma) and 61–57 Ma $^{40}Ar/^{39}Ar$ cooling ages on muscovite and Harlan *et. al.*, 2003; Bradley *et al.*, 2009). Detrital zircon age spectra from one sample document four Cretaceous peaks from 76 to 102 Ma, two Late Jurassic peaks at 155 and 166 Ma, three Early Jurassic to Late Triassic peaks at 186, 197, and 213 Ma, Carboniferous peaks at 303 and 346 Ma, and a Paleoproterozoic peak at 1828 Ma (Bradley *et al.*, 2009). Erosion of the Hatcher Pass schist into adjacent western Arkose Ridge Formation sections at Arkose Ridge and Willow Creek would be expected to generate schist clasts (Fig. 21) and Cretaceous detrital zircon ages (Fig. 36; Kortyna, 2011). However, the paucity of Jurassic and older detrital zircon age populations at Willow Creek and Arkose Ridge sections indicate the schist may not have been exhumed at the time of deposition. Detrital zircon grains from Arkose Ridge Formation sandstones at both Government Peak and Bald Mountain Ridge are dominated by Late Cretaceous (84–77) ages (Fig. 27) with U/Th ratios < 10 for all analyzed grains (Fig. 29). The complete absence of Precambrian, Paleozoic, Jurassic, and Triassic age detrital zircons in the Arkose Ridge Formation samples exposed west, south, and east of Hatcher Pass suggests the Hatcher Pass Schist was not a principle sediment source during deposition of the Arkose Ridge Formation (Fig. 35). All analyzed grains in the Government Peak area also yielded a <10 U/Th ratio, indicating the grains were not of metamorphic provenance (Fig. 34). Metamorphic detritus may have instead been derived from unmapped Cretaceous–Paleogene schist associated with contact metamorphism resulting from emplacement of Cretaceous continental-arc plutons (e.g. side or roof pendants to the 75–72 Ma Willow Pluton). Such pendants may have been eroded following Paleogene deposition of the Arkose Ridge Formation. Alternatively, metamorphic pendants may not yet be recognized given that Jurassic–Cretaceous plutons making up the Talkeetna Mountains have not been mapped in detail beyond the original 1:250,000 scale mapping carried out by the U.S. Geological Survey.

Regional Tectonic Implications

During Late Cretaceous time, marine sedimentary strata were deposited in a >90 km long forearc basin located between a continental-margin arc to the north and a coeval trench-accretionary prism to the south (Trop, 2008). Subduction of a mid-ocean spreading ridge beneath the southern margin of Alaska during the Paleocene changed the nature of sediment accumulation and magmatism (Bradley *et al.*, 2003; Cole *et al.*, 2006; Trop and Ridgway, 2007). Diagnostic evidence of spreading ridge subduction includes plutonic and volcanic rocks in the trench and forearc parts of the convergent margin as well as the geochemical signature of depleted mantle sources for these igneous rocks (Lytwyn *et al.*, 2000; Bradley *et al.*, 2003; Cole and Stewart, 2008) and high-temperature-low pressure metamorphic rocks in the accretionary prism (Sisson *et al.*, 1989). However, the sedimentary record of ridge subduction processes in basins positioned between the accretionary prism and magmatic arc has received far less attention. The Arkose Ridge Formation was deposited coeval with spreading ridge subduction based on 295 new U-Pb individual zircon grain analyses from 14 tuffs and ^{40}Ar-^{39}Ar ages from lavas (Idleman *et al.*, 2011). These ages are consistent with the maximum depositional ages from Arkose Ridge Formation sandstones at Willow Creek

(58.7 ± 0.89 Ma; Fig. 29) and eastern sections (59–60 Ma; Kortyna, 2011). These ages overlap the ages of near trench plutons interpreted as the product of ridge subduction in the accretionary prism exposed south of the forearc strata (Bradley *et al*., 2003). Paleocene–Eocene igneous intrusions, interpreted as near-trench plutons, document migration of a spreading ridge from west to east (older ages in west; younger ages in east) as the ridge was subducted diachronously beneath the southern margin of Alaska (Fig. 1). Deposition of Arkose Ridge Formation strata during a well-documented episode of spreading ridge subduction provides valuable insight on how spreading ridge subduction impacts and alters volcanism and sediment deposition within a forearc basin.

Prior to spreading ridge subduction in the Matanuska Valley-Talkeetna Mountain forearc basin, the Upper Cretaceous Matanuska Formation records mostly marine sediment deposited on a trenchward-dipping (southward) submarine slope under “normal” magmatic arc-forearc basin-accretionary prism relationships (Ridgway *et al*., 2012). The development of the basinwide angular unconformity between the Matanuska Formation and Upper Paleocene–Lower Eocene nonmarine deposits of the Chickaloon and Arkose Ridge Formation is correlated to tectonic uplift of the forearc basin as a result from the subduction of progressively younger oceanic crust in front of a spreading ridge (Trop *et al*., 2003; Trop, 2008). The younger, more buoyant oceanic crust was subducted at a shallow angle, resulting in the termination of continental-arc magmatism, erosion of the volcanic edifice, exhumation of the volcanic plutons, and subaerial exposure and erosion of formerly marine forearc deposits. Passage of the spreading ridge slab-window from underneath the forearc region during the Paleocene–Eocene caused rapid subsidence and allowed renewed sedimentation within the forearc basin (Arkose Ridge and Chickaloon Formation) during a 4–5 m.y time interval between 61–56 Ma (This study; Idleman *et al*., 2011). Coeval construction of the Caribou Creek volcanic center (59–36 Ma) east of the Talkeetna Mountains (Fig. 1) occurred as a result from slab-window magmatism beneath the structurally weak regional zone caused by the counterclockwise oroclinal bending of Alaska (Fig. 2; Cole *et al.*, 2006).

Conventional models of sediment deposition within forearc basins predict sediment derivation coeval with volcanism and plutonism in the arc massif as a response to first-order subduction of typical oceanic crust (Dickinson, 1995). The tectonic framework of the Matanuska Valley-Talkeetna Mountain forearc basin was altered due to the second-order tectonic process of spreading ridge subduction, causing deviation from the typical forearc basin depositional model. The onlap of Arkose Ridge Formation nonmarine strata and lavas directly on the arc massif is a distinct deviation from the conventional forearc basin depositional model of progressive infilling from marine to nonmarine strata (Dickinson, 1995). Changes in provenance along strike between Arkose Ridge Formation sections is attributed to variations in source terranes exposed directly north of present locations of Arkose Ridge Formation strata. Western Arkose Ridge Formation fluvial systems eroded sparse volcanic detritus, with exception of the Willow Creek section, and abundant 99–60 Ma detrital zircons from Createaceous–Paleocene arc plutons presently exposed in the Talkeetna Mountains. Eastern Arkose Ridge fluvial systems eroded abundant volcanic detritus and <60 Ma detrital zircons from the Caribou Creek Volcanic Center to the east (Table 7; Fig. 32).

The Eocene (59–36 Ma) Caribou Creek Volcanic Center, formed by slab-window magmatism from spreading ridge subduction, was an important source of detritus during deposition of eastern Arkose Ridge Formation sections (Kortyna, 2011). Similarly, lavas exposed north of Willow Creek near Willow Bench and Kashwitna River Bluff are interpreted to be important sources of detritus during deposition of western Arkose Ridge Formation strata. Thick packages of lavas and high percentages of volcanic detritus in both the Box Canyon (east) and Willow Creek (west) section support sediment derivation from these active proximal volcanic source terranes. Conventional models of sediment deposition within forearc basins predict sediment derivation coeval with volcanism and plutonism in the arc massif as a response to first-order subduction along convergent margins (Dickinson, 1995). Older plutonic detritus eroded from the Cretaceous–Paleocene arc massif is syndepositional with Eocene volcanic detritus indicating the remnant Cretaceous–Paleocene arc massif had to be uplifted, exhumed, and eroded coeval with construction and erosion of the Caribou Creek Volcanic Center in the eastern Talkeetna Mountains. This shows volcanic detritus in Arkose Ridge Formation strata is sourced from younger volcanic source terranes and there is an absence of volcanic detritus from the volcanic edifice correlated to the Cretaeous–Paleocene arc plutonic sources. This relationship indicates deviation from conventional models of forearc deposition.

Plutonic-volcanic detritus in Arkose Ridge Formation conglomerates and mafic lavas directly onlap the underlying Willow granitoid and provide a temporal constraint for the tectonic model of ridge subduction. Erosion of Cretaceous–Paleocene remnant arc plutonic source terranes by 59 Ma (maximum depositional age of Arkose Ridge Formation; Fig. 30) indicate pluton emplacement between 75–65 Ma, subaerial exposure by 59 Ma, and subsidence coeval with erosion between 59–55 Ma. The exhumation history of the Cretaceous granitoid underlying the Willow Creek section is constrained by 67–71 Ma cooling ages from plagioclase, biotite, muscovite, and zircon (Bleick *et al.*, 2009; Harlan *et al.*, 2003). Ongoing geochronology of lavas at the Willow Bench and Kashwitna River Bluff will aid in determining a more precise estimation for the amount of time missing between emplacement of underlying granitoid and deposition of lava. An accurate time interval will provide significant insight to how fast uplift and subsequent subsidence occurred in the Matanuska Valley-Talkeetna Mountain forearc basin as a result from spreading ridge subduction.

Another temporal constraint is documented along Bald Mountain Ridge where Arkose Ridge Formation sandstone (enriched in 82–79 Ma detrital grains) unconformably overly discontinuous, local exposures of 80 Ma granitoid and is faulted against Hatcher Pass schist (Fig. 10). The depositional age of the Hatcher Pass schist (77–61 Ma; Bradley *et al.*, 2009) suggests a number of protolith possibilities that are proximal to the current location of exposed schist. The Matanuska Formation and Valdez assemblage, exposed south of the Hatcher Pass schist (Fig. 3), represent two protolith possibilities due to overlap of depositional ages and relative location to the schist. When comparing detrital spectra from the Matanuska Formation and Valdez to the detrital spectra from the schist, there is a higher degree of overlap and similarity of the schist detrital ages to the Valdez ages (Fig. 37). Refer to Bradley (2009) for a detailed discussion on protolith possibilities of the Hatcher Pass schist. The Arkose Ridge Formation-schist-granitoid age relationships imply that the granitoid pluton (80 Ma) was emplaced prior to deposition of the protolith of the Hatcher Pass schist (77–61 maximum depositional age) and was subaerially exposed by the time of Arkose Ridge Formation deposition (59–57 Ma). Progressive flat-slab subduction of buoyant oceanic crust likely caused cessation of arc magmatism and uplift of the pluton. Further flat slab subduction and the passage of the slab window would be expected to form extensional structures, such as low-angle faults observed in the Government Peak area and possible interpreted fissure eruptive centers represented by lava successions exposed north of Willow Creek. The discontinuous exposures of the granitoid intrusions in the Government Peak area suggest the low-angle normal fault propagated through a portion of the pluton, causing parts of the pluton to become caught up in the hanging wall. As the granitoid was faulted upwards and exhumed in the footwall, coeval deposition of Arkose Ridge Formation was deposited upon the granitoid on the hanging wall side of the detachment fault, enriched in the granitoid detritus from the eroding footwall (Fig. 38). Rapid uplift and exhumation of the granitoid followed by subsidence with passage of the slab window resulted in accumulation of a thick succession of Arkose Ridge Formation directly upon the pluton as the schist was faulted up to surface. The schist yields 59–60 Ma cooling ages, consistent with uplift during deposition of the Arkose Ridge Formation.

Sedimentologic, geochronologic, and compositional data collected from the southern Talkeetna Mountains in the Arkose Ridge Formation documents Late Paleocene–Early Eocene uplift and subsequent subsidence of the northern Matanuska

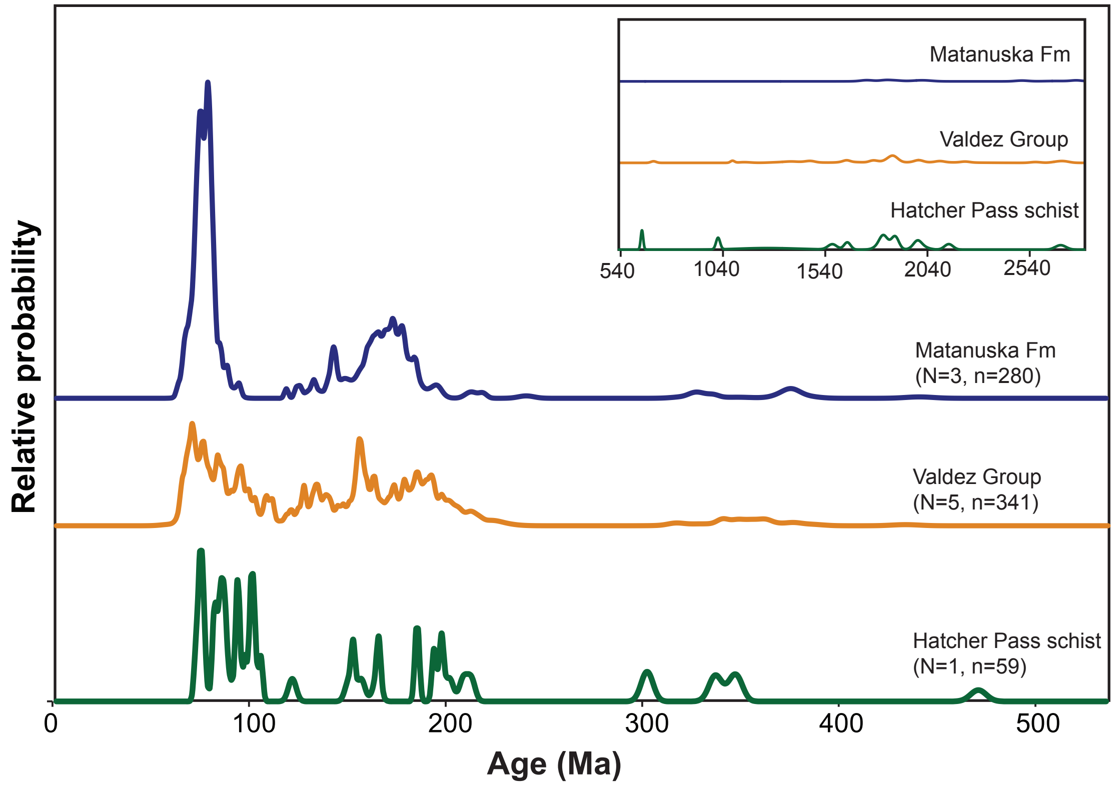
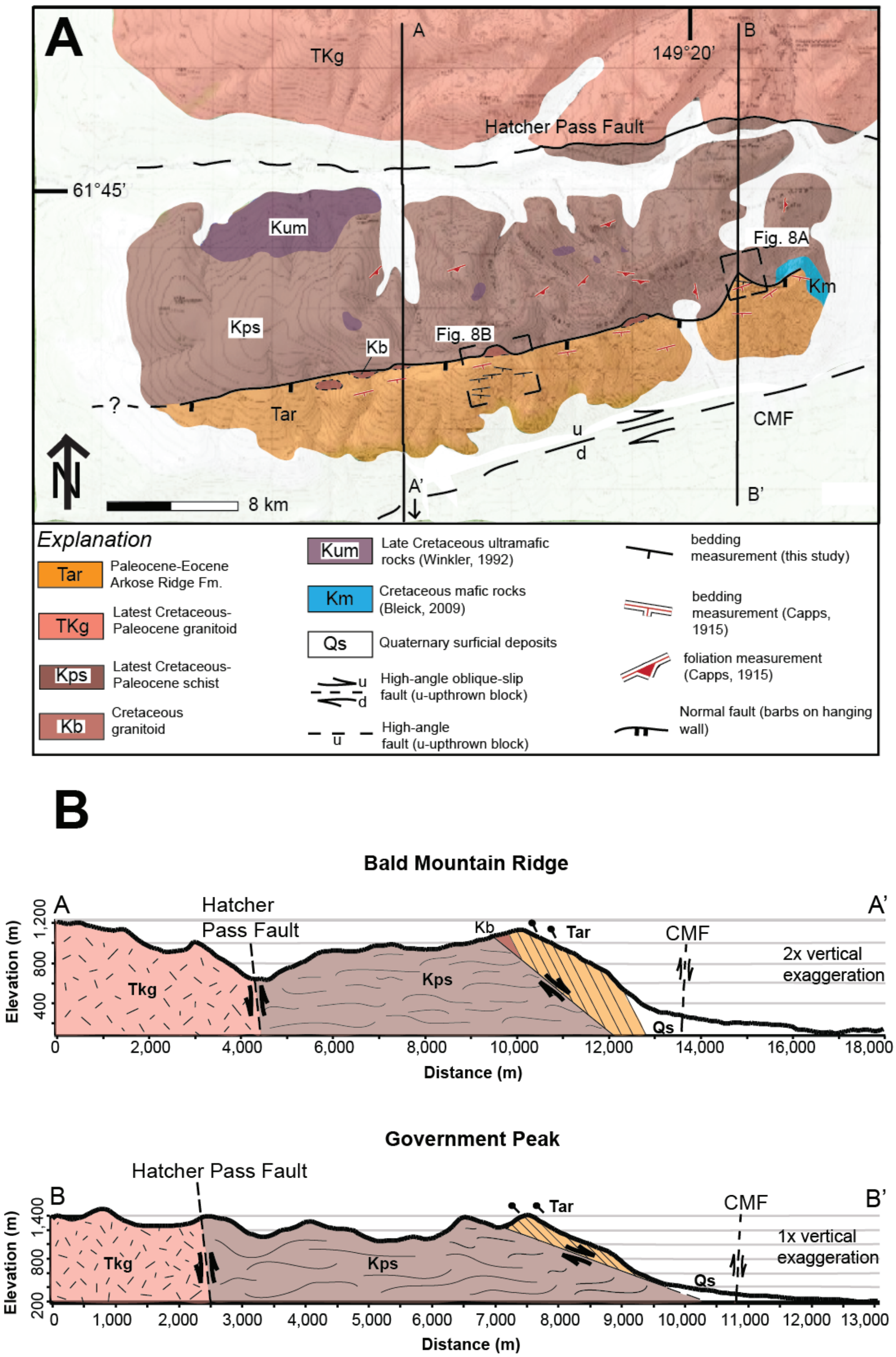


Figure 37. Age probability plots showing distribution of U-Pb age determinations up to 540 Ma for detrital zircon grains from the Hatcher Pass schist (green), Valdez Group (orange), and the Matanuska Formation (blue). Ages represent individual spot analyses from separate detrital zircon grains. U-Pb ages are plotted as a normalized relative-probability distribution (Ludwig, 2003). Relative heights of peaks correspond to statistical significance. The inset shows distribution of U-Pb age determinations between 540-2540 Ma of the same samples. There are nine detrital zircon grains from 1750 to 2150 Ma from the Matanuska Formation and 28 detrital zircon grains from 1452 to 2255 Ma from the Valdez Group that overlap the 1540-2040 Ma age population in the schist. N = total number of samples, n = total number of zircon grains.

Figure 38. (A) Enlarged generalized geologic map of the Government Peak area showing bedding measurements from this study and bedding and foliation measurements from Capps (1915). (B) Cross sections through Bald Mountain Ridge and Government Peak showing contact and structural relationships between the Arkose Ridge Formation, discontinuous granitoid lenses, and the Hatcher Pass schist. Bedding of strata in the Arkose Ridge Formation dip 45 degrees to the south and the normal fault plane between the Arkose Ridge Formation and Hatcher Pass schist dips 20 degrees to the south. The dip of the fault and bedding of Arkose Ridge Formation strata in the Bald Mountain Ridge cross section (A-A') has been corrected for 2x vertical exaggeration. The cross section line is defined by A-A' and B-B' lines on the generalized geologic map (A). The southern extent of cross section A-A' extends beyond the area defined by the map in (A) but is fully displayed in Figure 4.

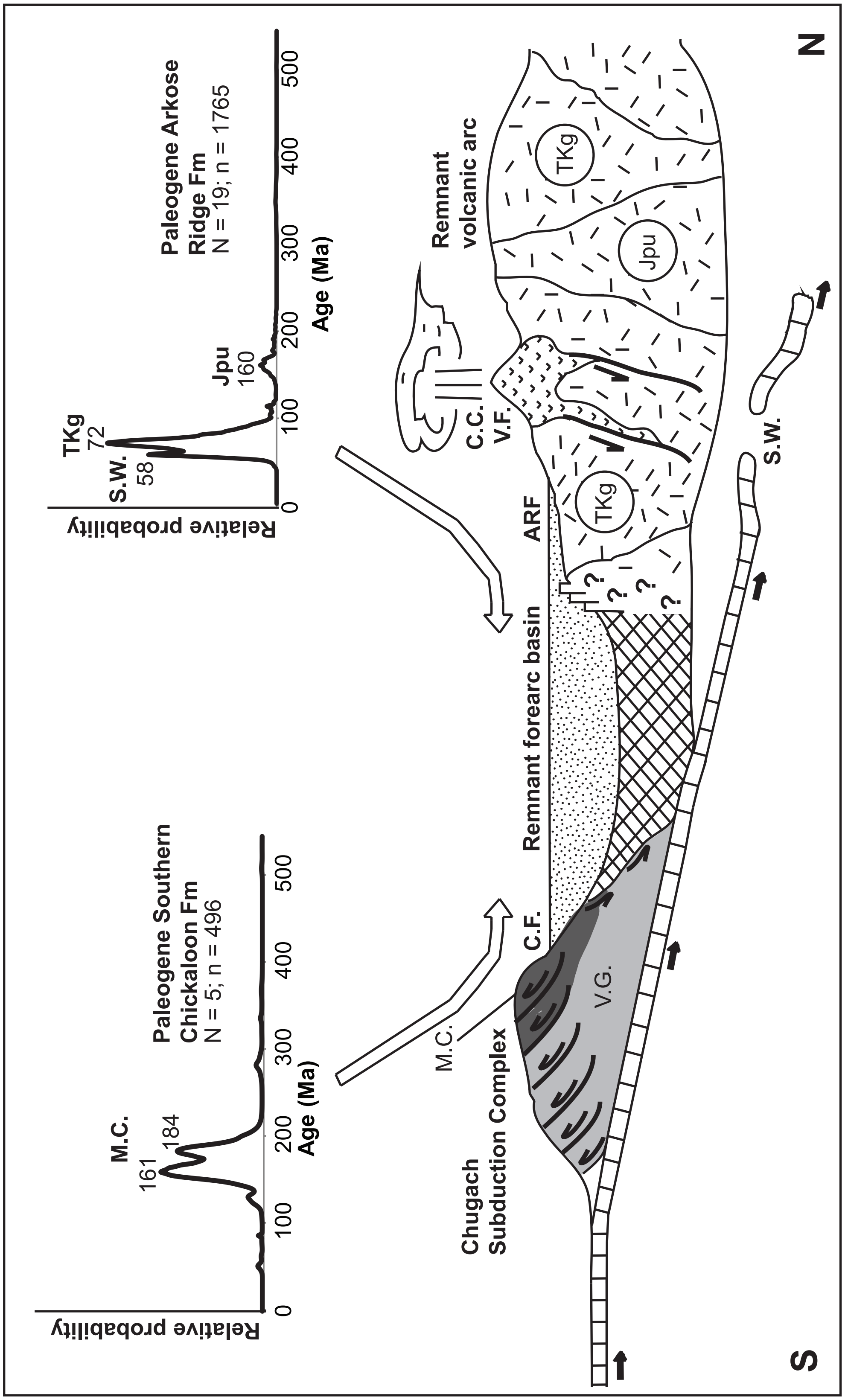

A
TKg
A
B
149°20'
Hatcher Pass Fault
61°45'
Kum
Fig. 8A
Km
Kps
Kb
Fig. 8B
?
Tar
u
d
CMF
A'
B'
N
8 km
Explanation
Tar Paleocene-Eocene Arkose Ridge Fm.
TKg Latest Cretaceous-Paleocene granitoid
Kps Latest Cretaceous-Paleocene schist
Kb Cretaceous granitoid
Kum Late Cretaceous ultramafic rocks (Winkler, 1992)
Km Cretaceous mafic rocks (Bleick, 2009)
Qs Quaternary surficial deposits
u d High-angle oblique-slip fault (u-upthrown block)
u High-angle fault (u-upthrown block)
bedding measurement (this study)
bedding measurement (Capps, 1915)
foliation measurement (Capps, 1915)
Normal fault (barbs on hanging wall)
B
Bald Mountain Ridge
A
A'
Hatcher Pass Fault
Kb
Tar
CMF
2x vertical exaggeration
Tkg
Kps
Qs
Elevation (m)
400
800
1,200
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
Distance (m)
Government Peak
Hatcher Pass Fault
B
B'
Tar
CMF
1x vertical exaggeration
Tkg
Kps
Qs
Elevation (m)
200
800
1,400
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000
13,000
Distance (m)

Valley-Talkeetna Mountain forearc basin. This uplift and subsidence is documented by the unconformity between Arkose Ridge Formation strata and underlying Cretaceous to Jurassic plutons. New geologic mapping of the southernmost strata of the Chickaloon Formation also documents a depositional unconformity between Chickaloon sedimentary strata and the underlying subduction complex sediments in the northernmost Chugach Mountains (Little, 1988; Trop *et al.*, 2003), suggesting uplift of the southern Matanuska Valley-Talkeetna Mountain forearc basin and Chugach subduction complex. Evidence for uplift in both sides of the forearc basin is consistent with a spreading ridge being subducted beneath southern Alaska, including uplift of the entire Matanuska Valley-Talkeetna Mountain forearc basin along with the associated subduction complex and volcanic arc, forming a double-sided forearc basin (Fig. 39). South-directed paleocurrent measurements from Arkose Ridge Formation strata in the southern Talkeetna Mountains, and north-directed paleocurrent indicators from the Chickaloon Formation in the northern Chugach Mountains, indicate sediment was being deposited from opposite sides of the forearc basin. Comparison of detrital zircon age signatures from the Arkose Ridge Formation to the Chickaloon Formation shows that basin-margin strata yield significantly different detrital age spectra (Fig. 39). Samples of the Chickaloon Formation, adjacent to the subduction complex, exhibit a narrow range of Early Jurassic to Early Cretaceous detrital zircon ages, whereas Arkose Ridge Formation samples are dominated by Late Cretaceous to Paleocene and subordinate Jurassic detrital zircon ages. Arkose Ridge Formation samples also yield a subordinate Eocene detrital zircon age population, and this is correlated to detritus eroded from the Caribou Creek volcanic field, which formed as a result of slab window magmatism as a spreading ridge was subducted beneath the area (Fig. 39). This suggests that as a spreading ridge was subducted beneath south-central Alaska, uplift of the entire subduction complex, forearc basin, and volcanic arc occurred. This was followed by erosion of the volcanic arc edifice and exhumation of plutonic sources to the north of the forearc basin, and exhumation and erosion of McHugh and Valdez Groups to the south of the forearc basin. As the spreading ridge passed through the area, subsidence in the forearc basin and erosion of these newly exhumed source terranes was followed by deposition of these sediments into a two-sided forearc basin and progressive infilling of the basin. Integrating the paleocurrent indicators, detrital zircon age populations, and sedimentologic data from both formations documents that northward-prograding gravelly alluvial fans of the Chickaloon Formation were eroding subduction complex material from the south (Little, 1998; Trop *et al.*, 2003), and southward-prograding fluvial-alluvial fans of the Arkose Ridge Formation were eroding the remnant volcanic arc plutons from the north into an axial braided stream system within the remnant forearc basin (Fig. 39). Subsidence and sediment accumulation ceased during the Oligocene time in response to shortening and uplift associated with flat-slab subduction of the Yakutat terrane beneath south-central Alaska (Finzel *et al.*, 2011).

CONCLUSIONS

New geologic mapping, compositional data, and detrital zircon ages from Arkose Ridge Formation strata exposed at Willow Creek document the depositional

Figure 39. Schematic cartoon showing tectonic setting and provenance during deposition of the Arkose Ridge Formation (ARF) and the Chickaloon Formation (CF) in the Matanuska Valley-Talkeetna Mountain forearc basin. Detrital probability plots for the Arkose Ridge Formation combine all detrital samples from this study and Kortyna (2011). See Table 7 for all ages. The Chickaloon Formation detrital probability plot combines all detrital samples collected from the northern Chugach Mountains (Trop, unpublished data). The dark gray shaded area in the most northern Chugach Mountains represents the oldest portion of the Chugach subduction complex and the terrane supplying detritus to the Chickaloon Formation. White arrows show paleocurrent direction. Abbreviations: ARF-Arkose Ridge Formation; CF-Chickaloon Formation; SW-Slab window; CCVF-Caribou Creek Volcanic Field; TKg-Latest Cretaceous-Paleocene pluton; Jpu-Middle to Late Jurassic plutons; MC-McHugh Complex; VG-Valdez Group.



Relative probability
0
100
200
300
400
500
Age (Ma)
M.C.
161
184
Paleogene Southern
Chickaloon Fm
N = 5; n = 496
Relative probability
S.W.
58
TKg
72
Jpu
160
0
100
200
300
400
500
Age (Ma)
Paleogene Arkose
Ridge Fm
N = 19; n = 1765
Chugach
Subduction Complex
M.C.
V.G.
C.F.
Remnant forearc basin
ARF
C.C.
V.F.
Remnant
volcanic arc
TKg
Jpu
TKg
S.W.
S
N

environments and erosional history of northern source terranes of the westernmost Matanuska Valley-Talkeetna Mountains forearc basin during Paleocene–Eocene time. Geologic mapping north of Willow Creek at Willow Bench and Kashwitna River Bluff documents mafic lavas inferred to be deposited by fissure eruptive centers. Measured stratigraphic sections and mapping at Willow Creek document a depositional unconformity between Arkose Ridge Formation strata and the underlying Cretaceous granitoid. Arkose Ridge Formation strata are dominated by pebble-cobble-boulder conglomerate, coarse-grained sandstone, and mafic lava flows deposited by debris flow/hyperconcentrated flow, streamflow, and effusive volcanic eruptions on high-gradient braided stream systems. Compositional data shows detritus dominated by plutonic and volcanic clasts in conglomerate and feldspar, monocrystalline quartz, plutonic grains, and subordinate volcanic and metamorphic lithic grains in sandstone. Age probability curves show all U-Pb ages of detrital zircons in sandstone are between 200–57 Ma with a major peak at 73–72 Ma and minor peaks at 88 Ma and 114 Ma. Three granitoid clasts from yield U-Pb zircon ages of Latest Cretaceous (81–69 Ma), early Late Cretaceous (89–82 Ma), and Early Jurassic to Latest Triassic (215–190 Ma), supporting erosion of proximal granitoid source terranes. The main detrital age population from sandstone and a granitoid clast match the 73.5–72 Ma U-Pb zircons ages of the underlying granitoid at the Willow Creek section. The Late Paleocene depositional age of the Willow Creek section is established by integrating 59–57 Ma detrital zircon maximum depositional ages with a previously published low-precision K-Ar age of 56.2 ± 1.7 Ma from a lava interbed at Willow Creek. U-Pb ages of 160 detrital zircon grains from two Arkose Ridge Formation sandstone samples from the Government Peak area, 20 km southeast of Willow Creek, reveal a Late Cretaceous (97–69 Ma) age distribution and a peak age at 79 Ma. This age population matches the Late Cretaceous U-Pb zircon ages (86–79 Ma) from the underlying granitoid pluton at that location. Geochronologic and compositional data, combined with south-directed paleocurrent measurements at Willow Creek and Government Peak, are consistent with sediment derivation mainly from Jurassic, Cretaceous, and Paleocene plutonic and volcanic source terranes exposed north of the basinal strata.

Comparison of Willow Creek strata to lithologically similar Arkose Ridge Formation strata exposed along strike in the southern Talkeetna Mountains provides valuable understanding of the depositional and tectonic framework of the Matanuska Valley-Talkeetna Mountains forearc basin. Western deposystems at Willow Creek, Government Peak area, Arkose Ridge, and Lava Mountain are dominated by plutonic detritus and Jurassic–Paleocene detrital ages, consistent with sediment derivation from Mesozoic arc plutons to the north. Eastern deposystems at Gray Ridge and Box Canyon are dominated by volcanic detritus and an abundance of Eocene detrital ages, consistent with erosion of the Caribou Creek volcanic field to the east. Willow Creek strata contain abundant volcanic clasts, differing from the overall westward trend of decreasing volcanic detritus. This change in provenance, together with the presence of thick-bedded lavas at Willow Creek, indicates the presence of a local Paleocene–Eocene eruptive center in the southwestern Talkeetna Mountains, remnants of which are preserved as mafic lavas between the Kashwitna River and Willow Creek. Overall, variations in stratigraphy and provenance between Arkose Ridge Formation sections support deposition within separate drainage basins which discharged into an axial braided stream system. Deposition was by varying alluvial-fluvial-lacustrine processes with sediment derivation from plutonic-volcanic source terranes dependent on location along strike within the forearc basin. Detritus was derived from both Jurassic–Early Paleocene remnant arc plutons and coeval volcanic centers, attributed to slab-window magmatism linked to late Paleocene–Eocene spreading ridge subduction. Provenance and stratigraphic data from all Arkose Ridge Formation sections document subaerial uplift of the forearc basin and exhumation of arc plutons followed by subsidence and renewed sediment accumulation coeval with volcanism. The subsidence and depositional history in the Matanuska Valley-Talkeetna Mountain forearc basin is a distinct deviation from typical forearc basin depositional and tectonic models and is consistent with tectonic models inferring spreading ridge subduction beneath southern Alaska.

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